2006

An Improved Approach To Watercolor Reproduction By Profile Editing

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An Improved Approach To Watercolor Reproduction By Profile Editing

by

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the School of Print Media in the College of Imaging Art and Sciences of the Rochester Institute of Technology

June 2006

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An Improved Approach To Watercolor Reproduction
By Profile Editing

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Acknowledgements

I would like to thank all the people whom were somehow involved in the journey of this research project. This thesis would not have been possible without the help and support of all of you.

I give countless thanks to my primary advisor, Professor Chung, for his valuable participation, patience and guidance throughout the research process. It was an awesome experience and an honor to learn from such an exceptional mentor.

I also thank the following people: Professor Frank Cost for his guidance and directions; all ten research participants, who allocated their time for this case study; Howard Vogl for sharing his research experiences; Dimitris Ploumidis for helping gather the ten research participants including himself; and especially, Professor Edline Chun for helping this research to reach its completion.

Last but not least, my parents, my brother, my sister-in-law, and my friends for their continuing patience, love and support in completion of my thesis.

Table of Contents

List of Tables

List of Figures

Abstract

Fine art is usually produced on paper or canvas as a one-of-a-kind artwork. Fine art may be reproduced in limited editions and put up for sale as art. Different printing technologies have been used in fine art reproduction such as lithography, screen-printing, and most recently inkjet.

The research aspect of watercolor reproduction has been the question of "how good is good enough." In this case, the artists demand the exact match between the original watercolor and its reproduction. While there are difficulties in quantifying the degree of color image match, the initial testing of watercolor reproduction using a color-managed approach with an inkjet printer showed that there is a need to improve the reproduction quality. The objective of this study is to see if accuracy of watercolor reproduction can be improved by using profile editing tools.

The significance of the research is the potential to achieve higher reproduction quality in watercolor by means of profile editing. In addition, we can put control back in the hands of content creators for limited editions.

This research begins with a literature review. The review discusses how artworks are being digitized and reproduced by museums. It points out the wide adoption of International Color Consortium (ICC) color management practices in printing and publishing. It also covers how a color image match between an original and its reproduction is assessed quantitatively and qualitatively.

The quantitative analyses of Macbeth ColorChecker between a generic ICC profile and a custom ICC profile were used to test first hypothesis, i.e., if there is any significant difference in measured color accuracy of watercolor reproductions between a generic ICC profile and a custom ICC profile. The results indicate that there is a significant difference in color accuracy of watercolor reproduction between using generic ICC profile and the custom ICC profile state findings. To our surprise, the custom ICC profile performed worse than the generic ICC profile. A possible cause of the large color differences was attributed to the accuracy of the scanner profile.

A paired comparison method was used to test the second hypothesis, i.e., if there is any significant visual difference in color accuracy of watercolor reproductions between an unedited ICC profile and an edited ICC profile. The results indicate that there is no significant difference in color accuracy of watercolor reproduction between an unedited ICC profile and an edited ICC profile state findings. To our surprise once again, edited profiles did not perform color matching any better than unedited profiles. A major factor is that editing of tone reproduction and gray balance are treated as two separate events in the profile editing process. In fact, tone reproduction and gray balance are dependent on each other.

Chapter 1

Introduction & Statement of the Problem

This research paper discussed and analyzed watercolor reproduction. This chapter will include a brief history of fine art reproduction, lithography, screen-printing, and digital printing. Also included will be a discussion of the problems encountered when attempting to make accurate color reproductions, specifically of watercolor paintings, and some possible solutions to those problems. Consideration of how modern color management technology can be used to solve color reproduction accuracy dilemmas is also given.

Background

Fine art is defined by Ackland Art Museum (2004) as "Art created for purely aesthetic expression, communication, or contemplation. Painting and sculpture are the best known of the fine arts" (Line 92).

Fine art is typically created on paper or canvas as one of a kind artwork. Fine art may be reproduced in limited editions and sold as art. Different printing technologies have been used in fine art reproduction. This section introduces the use of stone lithography, screen-printing, and inkjet for fine art reproduction.

Lithography

The use of lithography to produce fine art work began around 1815 (Kipphan, 2001, p. 1030). Stones with smooth, porous surfaces were used as artists' canvases and as the printing plate. Based on the "ink and water do not mix" principle, continuous-tone fine art prints were produced in quantities.

There are a number of disadvantages associated with producing fine art color by stone lithography. Artists need to know how colors are separated into different image carriers and how to transfer inked images from different image carriers in registration so that the resulting print represents the creative work of the artist. Toulouse-Lautrec (1864-1901) was famous for printed posters by stone lithography. His first color lithography, *La Goulue at the Moulin Rouge,* was produced in late1891 (Chapin, 2005, p. 51).

As color lithographic technology advanced, photomechanical color separation replaced manual color separation; thin aluminum plates replaced stone as the image carrier; multi-color rotary press replaced single-color platen press. Print media technology no longer was in the hands of the artists as stone lithography once was. The dichotomy between artwork creation and the fine art reproduction made color communication difficult and expensive for limited editions.

Screen-Printing

Screen-printing used stencil attached to gauze mesh as a master in the1880s (Dawson, 1981, p. 11). Artists would create line art of different shapes and colors for their artistic expression. Areas with open mesh allow the ink to flow through while areas with stencil prevent ink from flowing through. Fine art was reproduced by printing different stencils with inks of different color.

Similar to stone lithography, screen printing is a labor and materials intensive process. The process requires artists' labor, materials, and craftsmanship. The artistic endeavor is an integral part of the master creation and printmaking. It is logical to use screen printing for limited editions, but it does not provide the opportunity to print small quantities on demand.

Inkjet Printing

It is important to recognize that watercolor painting requires the use of paper as the creative medium. This would disqualify the use of either stone lithography or screen printing as the artistic medium. But watercolor reproduction can be reproduced with the inkjet printing technology.

Inkjet printing is the latest method that can be used for watercolor reproduction. There are three steps involved in fine art reproduction using digital imaging technologies, i.e., (1) capture the artwork by scanning; (2) edit or color manage the image; and

(3) print the image on demand. Digital printing, particularly inkjet, has become user-friendly as more stable colorants and a finer imaging head became available.

Color management and inkjet printing have advanced from being an experimental reproduction method to a preferred limited editions process for many artists. Most artists will only accept an almost perfect reproduction of their original works of art. The quality of the fine art reproduction by color-managed inkjet approaches the required level of perfection. In addition, the ease of use and the affordability of color management and inkjet printing have put fine art reproduction technology back in the hands of the artists. It allows limited fine art editions to be printed on demand with high quality.

The Problem

When artists demand very high quality from limited reproduction of their creative art, there is always a gray area of "how good is good." In addition, if digital imaging technology is easy enough to be used by artists themselves, then the other area of concern to be explored is to what extent the technology can be "tuned" to meet their quality expectations. Further elaboration regarding the problem of reproducing fine art requires looking at assessment issues as well as improvements in methodology.

Assessment of Accurate Color Reproduction

There is no clear methodology as to how accurate color reproduction is assessed. From literature review, accurate color reproduction may be assessed subjectively. When judging color image match subjectively between a fine art original and its reproduction, a layman may accept the match, but the artist will reject it. In other words, there is a potential discrepancy between being close and being exact (Chung, 2004, lecture notes).

Accurate color reproduction may be assessed objectively. This would involve (1) using of a synthetic test target representing color patches in a source image; (2) making colorimetric measurement of these color patches in both the source and its reproduction; and (3) analyzing the distribution of color differences (ΔE) found between the source and its reproduction (Chung and Shimamura, 2001, p. 334). It is assumed that the color matching analysis, based on the Macbeth ColorChecker, applies to the color matching between watercolor original and its reproduction. The smaller the ΔE distribution is, the closer match is between the two images. But there is no certainty that the two images will match based on the ΔE distribution alone. One probable cause of color image mismatch is macro-uniformity (Rasmussen, 2001, p. 90), which is visible in the form of color variations where may be one-dimensional (streaks and bands) or two-dimensional (e.g., mottle).

In this research, the researcher recognized that the first problem in fine art reproduction is the need for a clear methodology to assess the accuracy of color image reproduction. The researcher used both subjective color image evaluation and objective color image analysis to determine the degree of color match between a source image and its reproduction.

Improved Methodology for Fine Art Reproduction

Watercolor paintings are classified as reflective originals. A scanner is used to capture the reflective original as an RGB file. The image is then displayed on a monitor. To output the RGB image as a hard copy reproduction, it is necessary to convert the image from its RGB color space to the CMYK color space. This conversion is also termed color management.

Color management was implemented via proprietary technologies in the 1980s. This meant an expensive investment in equipment that required skilled operators to make it work. In the mid-1990s ICC-based color management, based on an open-system concept, introduced an affordable solution using modern microcomputer systems. While a layman can produce acceptable color image reproduction routinely, using ICC-based color management technology to produce exact color image reproduction is still a challenging task.

In this research, the researcher recognized that a problem in fine art reproduction is the need for an improved approach to achieve accurate color image reproduction. The researcher tested the color matching performance of a generic printer profile versus a custom printer profile. In addition, the researcher experimented with the use of profile editing tools to improve the color matching performance.

Motivation to Conduct the Study

There are three aspects of motivation as to why this is the right topic to study at the right time. It begins with a brief mention of personal interest. It then points out that media technology is back in the hands of content creators. And finally, a pilot study suggests that there is room for an improved color image reproduction if the artist can exploit color-managed fine art limited editions.

Personal Interest

As a fine artist who has a keen interest in printing technology, the researcher wanted to learn how modern color management technology works for fine art color reproduction. In addition, she wanted to experiment with the idea of optimizing color image match through the use of profile editing tools whereby the results can be substantiated by color image assessment.

Media Technology is Back in the Hands of Content Creators

Limited fine art reproduction required the efforts from two groups of people in 1980s. Artists had control as content creators and media specialists addressed the technology of color management and print. Many iterations were required between artists and printers to get the color right.

The goal of an ICC color management system is to create and promote the standardization of an open, vendor-neutral color management system. The ICC-based color management technology has the following features: (1) it is cross-platform; (2) it is capable of constructing custom ICC profiles; and (3) it offers profile editing tools. All of these technologies are available in the Color Management Science (CMS) Laboratory at Rochester Institute of Technology. In a sense, the availability of the color management technology and inkjet printing technology has put graphic media tools back in the hands of content creators.

Pilot Study

Three watercolor paintings were secured, courtesy of Professor Luvon Sheppard of Rochester Institute of Technology, for this study. When reproducing artwork using ICC-based color management workflow, the researcher found visible color differences between watercolor reproduction and its original.

Causes of color differences between the artwork and its reproduction may come from inconsistency of the inkjet printer or from the inaccuracy of the profile. According to Joel Chan (1999, p. 65), inkjet technology is quite consistent. Thus, this work will look into the opportunity of profile editing for improved color image reproduction.

Chapter 2

Review of Literature

This chapter provides a review of literature in three aspects of this research. First, the researcher reviewed how artworks were being preserved, digitized, and rendered by museums. Then, the researcher discussed the wide adoption of International Color Consortium (ICC) color management practices for printing and publishing and points out the opportunity for improved color matching through profile editing. Finally, the researcher reviewed how color image match between an original and its reproduction can be assessed.

Preserving, Digitizing, and Reproducing Artwork

The importance of preserving artwork is of relevance to the proposed study. A case in mind was the research of Roy Berns of the Munsell Color Science Laboratory (MCSL) at Rochester Institute of Technology (RIT) on how he used color science to rescue art (National Public Radio Morning Edition, 2005). The concern was about artworks that fade which can ruin the artists' creative intent. Professor Berns demonstrated how digital rejuvenation works by performing chemical analyses of ingredients used in a painting. By creating a simulation of the old painting as if it were new, he created spectral matching, as opposed to a colorimetric match, between the original painting and the reproduction.

Spectral color imaging uses devices to capture, process, and print more than three channels of spectral data to produce spectrally accurate reproductions. Spectral reproductions match the original artwork over many different illumination conditions and usually do not require manual color adjustments to produce a good match. Such systems, however, are based on custom hardware that can be very expensive and require a trained operator. Fine art reproduction workflows based on standard three-channel capturing devices and hardware are more affordable because the equipment is readily available. In this research, the researcher used ICC-based standard three-channel capturing devices for imaging capture and color image reproduction.

The approach to how artworks are being digitized and rendered by museums is of interest to the research. Much effort has gone into digitizing and archiving artworks in museums. Research projects started in the early 1980s demonstrating the usefulness of image processing methods as convenient assistants to the curators working in the field of cultural heritage (Bartolini et al., 2003). These projects paved the way to develop new tools for the needs of museums and cultural heritage workers. By the end of the '80s, digital imaging was developing at a rapid pace. New devices made it possible to acquire higher resolution images while spending less time; new storage devices made it possible to store an increasing amount of information regarding an increasing number of images; and computers became faster, making it possible to develop new powerful algorithms able to process this increasing amount of information. These new tools and their capabilities have enabled museums interested in digital images to move from low-quality representation of painting and sculptures, used only for archiving aims, toward an interactive way of managing high-quality representations.

The survey conducted by MCSL showed variance of similar artwork being digitized and reproduced (Berns and Frey, 2005). Figure 2.1 provides a visual summary of the variance in color appearance of two paintings by four museums.

Figure 2.1. Color variance of two paintings (Berns and Frey, 2005)

International Color Consortium (ICC) Color Management Practices

A few articles in *Test Targets 4.0* demonstrated how ICC color management performance has been viewed positively from testing done at RIT and elsewhere (*Test Targets*, 2004). The challenge to accurately reproduce an artist's watercolor and meet his stringent color matching requirements still exists. The idea of improving ICC color management through profile editing seems to be a possible solution. This section reviewed literature pertaining to ICC color management performance plus software packages that provide profile editing features.

ICC color management began in 1993 as a process that controls the exchange and reproduction of images across a wide range of devices. The goal of color management is to create, to promote, and to encourage the evolution and standardization of open-vendor platform, color management system architecture and component known as color management systems (International Color Consortium, 2004).

Color-managed workflows have been implemented with success. A color management system, or CMS, allows any color device, such as monitor, scanner, camera, and printer, to be defined in terms of a standard model of color space through a device "profile," i.e., input profile, output profile, and display profile.

There are two main profiles. A generic profile is printer profile and a custom profile is profile-making software. The generic profile is usually supplied by any manufacturer for a device. The generic profile is in general accessible from the vendor's web site or provided with the driver software. A generic profile is an average device. The custom profile is mostly done with color management. The custom profile refers to a profile that is made specifically for a user's device. The researcher needs a test chart, a measuring instrument, and profile-making software to make a custom profile for a scanner, monitor, or printer (Sharma, 2004).

The ICC profiles provide color management systems with the information necessary to transform the native color data of a device to device-independent color space. Guidelines set by the ICC define profile structures and other rules of today's color management systems. System-level color management modules (CMMs) provide utilities that any software can use for any color transformation task (What is color management?, 2000).

There are gaps and challenges that ICC color management faces in color image reproduction. Basically, ICC color management does a wonderful job in producing pleasing color image reproduction, as seen in magazine and newspaper publishing. As evidenced by museum artwork archiving, ICC color management performance in addressing accurate color reproduction has fallen short (MacDonald, Morovic, and Saunders, 1995).

The use of CMS has made possible the limitation imposed on the variables of problems because the CMS has not yet worked out the solution to all of the problems of color reproduction (Fleming and Sharma, 2002).

Color management permits management of color in a raw form of the collected facts and data throughout the printing process; only RGB or CMYK information is not enough. The ICC profiles contain tables with consistencies between RGB or CMYK and

L*a*b* values. It is possible to print more accurately a digital document on an inkjet printer with a good knowledge of color significance (Chagas, Blayo, and Giraud, 2004). The inkjet printer as demonstrated by this study is a methodology to obtain high-quality printing of a watercolor reproduction using profile editing tools.

Profile editing is something new in the 21st century, thus bringing us new hope. The use of profile editing tools is a way to improve the ICC color management performance. Textbooks, *Real World Color Management* (2003) by Fraser, Murphy, and Bunting, and *Understanding Color Management* (2004) by Sharma, have chapters about it. Fraser, Murphy, and Bunting described in Part II how they tried and tested techniques of building, evaluating, and editing profiles for creating, evaluating, tuning, and maintaining device profiles. Sharma described color management in terms of hardware such as measuring instruments; software such as profile making software and profile using software, charts such as IT8.7/1; and methodology such as conversion, characterization and calibration. Sharma also detailed a number of processes and programs that can be used to assess profile accuracy.

Assessing Color Image Reproduction

Color image may be judged by picture quality or by reproduction quality. Picture quality is assessed visually, based on the merit of the image itself and subjective responses of the judges are sought. On the other hand, the researcher assessed reproduction quality by judging how close the image resembles a reference. In this research, the researcher was interested in the reproduction quality of watercolor paintings where the original watercolor served as the reference.

There are two approaches in conducting reproduction quality analysis. The first approach is by conducting a colorimetric analysis of a color chart and the second approach is by conducting psychometric experiments, e.g., paired comparison.

When conducting colorimetric analysis of a color chart, the researcher assumes that the color chart, e.g., Macbeth ColorChecker, represents color contents found in the average artwork. By measuring and analyzing CIELAB values of the color patches between the original and its reproduction, the researcher is able to determine the agreement in hue, lightness, and saturation between the original and its reproduction. Pobboravsky and others have published some of the specific analysis techniques: (1) use of a synthetic test target, e.g., Macbeth ColorChecker, representing colors in the source; (2) make colorimetric measurement of the test target and its reproduction; and (3) analyze color difference (ΔE) between the original and its reproduction (Pobboravsky et al., 1971).

The researcher needed multiple samples and a reference to conduct the visual assessment using the paired comparison method. MacDonald, Morovic, and Saunders (1995) have published their work on paired comparison and recommended no single gamut mapping that serves all artwork reproduction because "a pairwise comparison method was used for three paintings under several different illumination conditions with a panel of observers. The results indicate that the optimum choice of colour gamut mapping procedure depends on the pictorial content of the painting" (p. 253).

The researcher collected three watercolor paintings and asked the judge, "which of the two samples matches the reference closer?" The non-parametric statistical analysis method not only answers which sample has the best reproduction quality, it also tests for consistency of the judges involved in the experiment (Naud, 1967).

Chapter 3

Hypothesis

As stated in Chapter 1, the objective of this study is to see if current watercolor reproduction can be improved by ICC-based color management and further improved by using profile editing tools.

There were two hypotheses tested in this study. The first hypothesis, stated in its null form, was that there was significant difference in color accuracy of watercolor reproduction between a pre-media workflow using a generic ICC profile and using a custom ICC profile.

The second hypothesis, stated in its null form, was that there was no visual significant difference in color accuracy of watercolor reproduction between a pre-media workflow using an unedited ICC profile and using an edited ICC profile.

The researcher set up the workflows tested in the laboratory and generated color reproduction samples. By means of quantitative analysis of color accuracy between color specified and color reproduced, the researcher tested the two hypotheses as stated.

The researcher had sufficient reasons to reject the first null hypothesis and the researcher accepted there was a significant difference in color accuracy of watercolor reproduction between a pre-media workflow using a generic ICC profile and using a custom ICC profile.

However, the researcher had sufficient reasons to fail to reject the second null hypothesis and the researcher accepted there was no visual significant difference in color accuracy of watercolor reproduction between a pre-media workflow using an unedited ICC profile and using an edited ICC profile.

Chapter 4

Methodology

The purpose of this research was assessing color image reproduction quality of watercolor paintings and seeing if watercolor reproduction could improve by ICC-based color management and further improved by using profile editing tools. This study provided an industry overview of measuring and analyzing CIELAB values of the color patches between the original and its reproduction. Moreover, the research presented data gathered for the benefit of further research in the field of ICC-based color management system with profile editing tools.

In this research, colorimetric values of the 24 patches in the Macbeth ColorChecker represented reference values. Colorimetric values of the reproduced ColorChecker represented sample values. Color differences, in the form of ΔE (ab), were a measure of the color matching performance of the ICC profile tested. The ΔE distributions between two ICC profile performances could be analyzed in the form of histogram or cumulative relative frequency (CRF) curves.

Shown in Figure 4.1 were the procedures that the researcher used to conduct the experiment, preparation, initial color-managed workflow, image evaluation, profile editing, and testing in color-managed workflow.

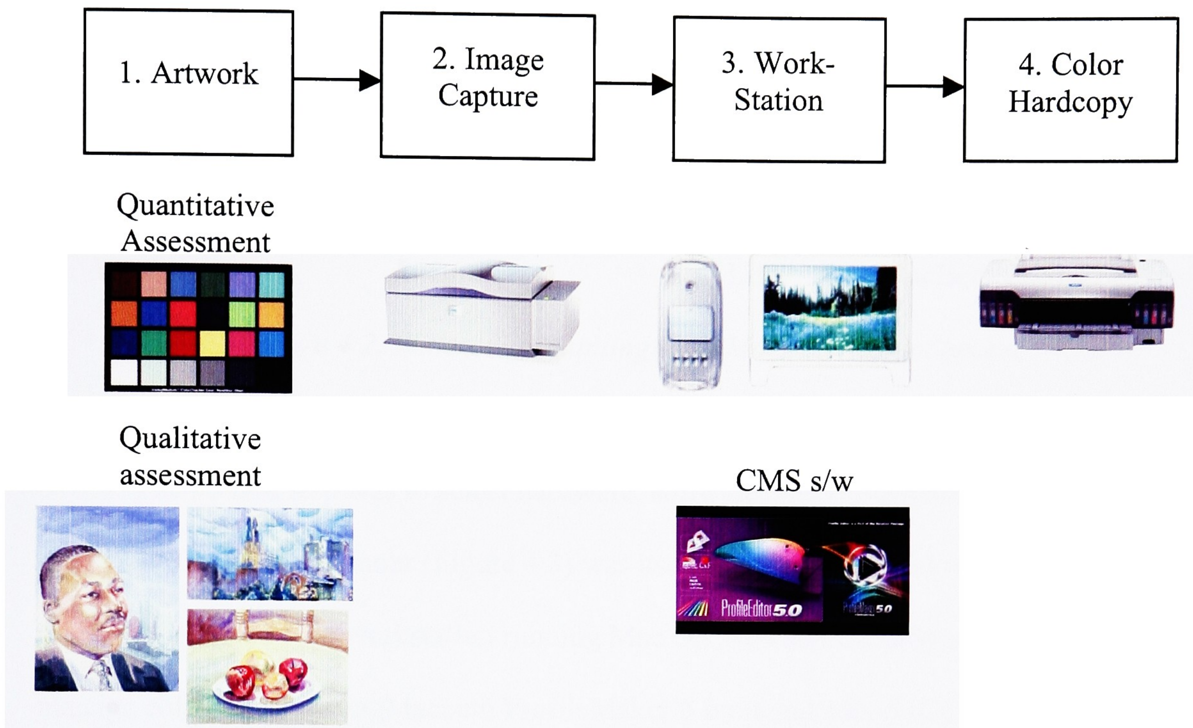


Figure 4.1. Color-Managed Workflow Used in the Research

Preparation

The first step was to select watercolor paintings. The following three watercolor paintings, Figure 4.2, courtesy of Professor Luvon Sheppard, were selected to represent landscape, portrait, and still life and will be referred to as *Landscape*, *Portrait*, and *Still Life*. In addition, the MacBeth ColorChecker was also selected for quantitative analysis.

Landscape Portrait Still Life MacBeth ColorChecker

Figure 4.2. Watercolor paintings and MacBeth ColorChecker

The second step was to select hardware, software, and consumable. In this study, the Scitex EverSmart scanner (Figure 4.3) was used to capture original watercolor paintings. A Macintosh workstation running Mac OS 10.4 and ColorSync 4.4 was used to manage color. The GreatagMacbeth ProfileMaker 5 built and edited ICC profiles. Adobe Photoshop CS served as the application programming interface (API). An Epson 4000 inkjet printer was used for hardcopy output (Figure 4.4).

Figure 4.3. Scitex EverSmart Scanner

Figure 4.4. Epson Stylus Pro 4000 Inkjet Printer

Initial Color-Managed Workflow

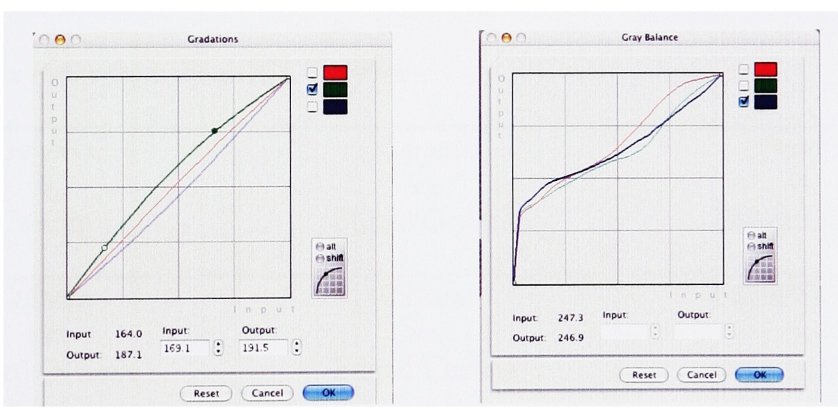
The third step was to test the first hypothesis, if there was significant difference in color accuracy of watercolor reproduction using a generic ICC profile versus using a custom ICC profile. The workflow began with scanning source images and the ColorChecker. The scanned images were opened as raw scans in Photoshop. The scanner profile was assigned to these images. These images were converted to the printer color space using generic and custom ICC profiles. The converted images were then output to the Epson 4000 inkjet printer.

Image Evaluation

The fourth step was testing the first null hypothesis, if there was no significant color difference in color reproduction quality between the generic and the custom profile. The step was designed to assess colorimetric accuracy of the Macbeth ColorChecker reproduction and see if there was a real difference using a generic ICC profile versus using a custom ICC profile.

Profile Editing

The fifth step was to edit both generic and custom ICC profiles using the 'Gradations' and 'Gray Balance' tools in ProfileMaker 5 to achieve better gray balance (Figure 4.5). The researcher edited the custom based on colorimetric analysis of the Macbeth ColorChecker and edited the generic profile based on visual inspection of the landscape reproduction by the following criteria. The edited profiles were saved for further testing.



Gradations Gray Balance

Figure 4.5. GMB Profile Editing Tools

The quantitative data, based on colorimetric analysis of the ColorChecker, was used when profile editing with ProfileMaker's profile editing tools. Specifically, the tone reproduction tool and the Gray Balance tool are used to adjust the profile such that deviations in tonal values are reduced while neutrality is preserved.

Testing Edited and Unedited Profiles in Color-managed Workflow

The final step was testing the second null hypothesis, if there was no visual significant color difference in color reproduction quality between unedited and editing profiles. Paired comparison method for visual assessment was used to determine if there were visual significant difference in color accuracy of watercolor reproduction among four samples; the custom ICC profile, the edited custom ICC profile, the generic ICC profile, and the edited generic ICC profiles, and six pairs as shown in Table 4.1.

Table 4.1 Six Pairs from Four ICC Profiles

Generic vs. Custom	Generic vs. Edited Generic	Generic vs. Edited Custom
Custom vs. Edited Generic	Custom vs. Edited Custom	Edited Generic vs. Edited Custom

Primary advisor Professor Robert Chung created a procedure for conducting the paired comparison test from Thurston's theory that was known as early as 1927 (Engeldrum, 2000). Chung developed a number of Excel templates to implement the paired comparison analysis at RIT. The document illustrates the procedure for preparing and conducting the test. The test is for consistency among judges when testing differences in samples by analysis of using three watercolor paintings samples. The full explanation of the paired comparison test can be found in the Appendix A.

Color Management System Laboratory in the School of Print Media at RIT offered Epson super B semi-gloss paper for printing the artwork. The researcher printed the test images of three original watercolor paintings. These images are known as Samples A (Unedited Generic profile), B (Edited Generic Profile), C (Unedited Custom Profile), and D (Edited Custom Profile). Pairs of samples as explained in Table 4.1 and originals were presented to judges randomly under standard viewing conditions.

The researcher had at least ten judges for the experiment. She conducted the paired comparison test for each judges, showed each pair of images in random and in different order, and asked each judge to mark the preferred image for accuracy between the pair. Using Chung's Excel templates, Table 4.2 shows 'x' the preferred as sample.

Table 4.2. Selected One Which More Accurate Between the Pairs by the Judges

Pair	Chosen One from the Pair by Consistency of Judges					Pair	Chosen One from the Pair by Inconsistency of Judges				
1	x	A	vs.		B	1	x	A	vs.		B
2		A	vs.	x	C	2		A	vs.	x	C
3	x	A	vs.		D	3		A	vs.	x	D
4		B	vs.	x	C	4	x	B	vs.		C
5	x	B	vs.		D	5		B	vs.	x	D
6	x	C	vs.		D	6		C	vs.	x	D

The researcher made sure that the images are linked to known treatments so that she could make inference regarding the meaning of the images in relation to data analysis and secure a standard viewing booth with D50 lighting.

The analyses are: (1) test for consistency of agreement among the judges, (2) find ranking preference, and (3) test for real differences among the prints. The analysis in tables and figure shown below was based on one of the three watercolor paintings, *Landscape.*

The researcher entered the data into Section A of the Excel template and analyzed the consistency of each judge after all the judges had finished. The spreadsheet automatically counted the number of times each sample received a mark. '0' was assigned to a sample if it received no mark. As shown in Table 4.3, the sum should be '6' for four samples. The spreadsheet automatically entered the tally count in the Section C and computed the number of triads. Shown in Table 4.4, "0' triad indicated that the judge is consistent. '1' triad indicated that the judge had one inconsistency, etc.

Table 4.3. Sum of '6' for Four Samples in Tally

Print	Count by Consistency of Judges	Print	Count by Inconsistency of Judges
A	2	A	1
B	1	B	1
C	3	C	1
D	0	D	3
Sum =	6	Sum =	6

Table 4.4. Triads Between Consistency (0) and Inconsistency of Judges (1)

Consistency of Judge					
Print	Row sum	Expected	$(R-E)^2$	Total	No. of Triads
A	2	1.5	0.25	5	0
B	1	1.5	0.25		
C	3	1.5	2.25		
D	0	1.5	2.25		
Inconsistency of Judge					
Print	Row sum	Expected	$(R-E)^2$	Total	No. of Triads
A	1	1.5	0.25	3	1
B	1	1.5	0.25		
C	1	1.5	2.25		
D	3	1.5	2.25		

In order to identify where the triad takes place, the researcher needed to construct a triad diagram, as shown in Figure 4.6. The first step was to place sample IDs on a piece of paper, then, drawn an arrow between two samples with the arrow pointing to the preferred sample. When a circular pattern is identified, i.e., A is better than B, B is better than C, and C is better than A, this marks a triad or an inconsistency of the judge. The researcher repeated the test for consistency of a judge, using the supplied spreadsheet, until all judges were analyzed.

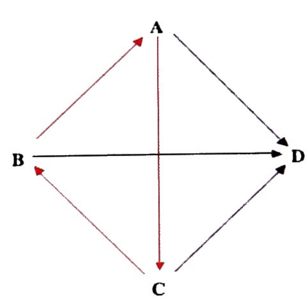


Figure 4.6. Triad Analysis

The researcher selected up to 7 judges to analyze their subjective responses. She picked consistent judges first before judges with triads. She noticed that averages were calculated for each of the five samples. The number was proportional to its preference status. If theses averages were far apart from one another, as shown in Table 4.6, chances were that the judges were in agreement with each other and the sample with the highest average was the most preferred image. The opposite would also be true. In order to claim there was a significant agreement among the judges or there was significant difference among the samples, the researcher continued.

Table 4.5. Responses of Consistent Judges

The subject matter	Evaluation of reproduction quality of link profiling s/w	
Date the experiment performed	4/19/05	
The number of judges participated	10	
The number of prints	4	

Print	Rank scores of all judges (add '1' to raw scores)										Ave.
	1	2	3	4	5	6	7	8	9	10	
A	4	3	4	4	3	4	3	3	2	3	3.30
B	3	1	1	1	4	1	2	3	2	3	2.10
C	1	4	2	2	2	2	4	3	2	1	2.30
D	2	2	3	3	1	3	1	1	4	3	2.30
Triad	0	0	0	0	0	0	0	1	1	1	

Note: Cut and paste row 10 -14 for consistent judges only.

Print	Judges who are consistent (0 triad)								Ave.		
	1	2	3	4	5	6	7			The number of judges who are consistent ----->	7
A	4	3	4	4	3	4	3		3.60		
B	3	1	1	1	4	1	2		2.00		
C	1	4	2	2	2	2	4		2.20		
D	2	2	3	3	1	3	1		2.20		

The spreadsheet automatically summarized the ranking order shown in Table 4.6 from the most preferred sample to the least preferred sample. At this point, it is appropriate to describe what these samples represented and what could be said about these samples based on judges' responses.

Table 4.6 Rank Ordering

		Description of Print Conditions
Best	A	Unedited Generic Profile
2nd	C	Unedited Custom Profile
3rd	D	Edited Custom Profile
Worst	B	Edited Generic Profile

Agreement among judges existed if the sum of squares (S), as shown in Table 4.7, was greater than the critical value form the supplied decision table. The correlation, R, was also calculated. If the 'R' value was higher than 0.7, there was a high level of agreement among the judges. If 'R' was low, then even if the judges agreed, the results were not strong enough to support any conclusion.

Table 4.7. Test for Consistency Among Judges

Print	Judges who are consistent							Col_9 Total for all judges	Col_10 *Average total (K37)	Col_11 Total - Average	Col_12 $(T-X)^2$
	1	2	3	4	5	6	7				
A	4	3	4	4	3	4	3	**25**	17.5	7.5	56.25
B	3	1	1	1	4	1	2	**13**		-4.5	20.25
C	1	4	2	2	2	2	4	**17**		-0.5	0.25
D	2	2	3	3	1	3	1	**15**		-2.5	6.25
Sum of all totals:								70		**Sum of squares (S):	83

Chapter 5

Results

To test the hypotheses of this thesis, two statistics, from the quantitative analysis of the Macbeth ColorChecker and from the visual analysis of the watercolor reproductions, were compared to the distances representing prints using a generic ICC profile, a custom ICC profile, an edited generic ICC profile, and an edited custom ICC profile for the objective of this study. The study is to see if accurate watercolor reproductions can be improved by ICC-based color management and further improved by using profile editing tools.

There were two hypotheses tested in this study. The first hypothesis, stated in its null form, is that there is no significant difference in color accuracy of watercolor reproduction of a pre-media workflow using a generic ICC profile and using a custom ICC profile.

The second hypothesis, stated in its null form, is that there is no visual significant difference in color accuracy of watercolor reproduction between a pre-media workflow of a generic ICC profile using an edited generic ICC profile, using a custom ICC profile, and using an edited custom ICC profile.

Hypotheses testing should demonstrate if there are any significant differences between a controlled condition and an experimental condition. For the first hypothesis, a generic profile represents a controlled condition and a custom profile represents an experimental condition.

The data from the quantitative analysis of the Macbeth ColorChecker between generic ICC profile and custom ICC profile was used to test the first hypothesis. While quantitative analyses of the Macbeth ColorChecker were used to edit ICC profiles, paired comparison analyses were used to test the second hypothesis, i.e., if there are significant differences in color accuracy of watercolor reproduction among generic ICC profile, edited generic ICC profile, custom ICC profile, and edited custom ICC profile.

The statistical method used to assess the data collected from the generic ICC profile and the custom ICC profile for the first hypothesis was a *t*-Test for percentages at a 95-percent confidence level. For the second hypothesis, paired comparison test on performance of the generic ICC profile, the edited generic ICC profile, the custom ICC profile, and the edited custom ICC profile were analyzed using Excel templates provided by Professor Chung; experimental results are included with the following exploration.

First Hypothesis Testing

The first null hypothesis (H_0) to be tested states is there are no significant differences in color matching performance between a generic ICC profile and a custom ICC profile. The alternative hypothesis (H_a) is there are significant differences in color matching performance between a generic ICC profile and a custom ICC profile.

The generic ICC profile was created with a scanner ICC profile and a printer ICC profile in controlled condition. The scanner ICC profile name was EverSmart_11905.icc and the printer ICC profile name was Pro4000P_semigloss.icc.

The custom ICC profile was created with the Epson 4000 Pro without any profile editing in experimental condition. The custom profile name was Epson 4000_03224.icc.

t-Test

The statistic *t* is used in determining the significance of differences of percentages. It is defined as the difference divided by the standard error of the difference. Its distribution shows the probabilities associated with this ratio for a given number of cases (American Society for Testing and Materials, 1968).

The *t*-test for percentage when used to test for the significance of the difference between two experimentally observed proportions would require using the formula for the standard error of the differences.

To compare two population or treatment means when the samples are paired, the researcher first translated the hypothesis of interest, i.e., the value of a mean of the generic ICC profile (μ_1) – a mean of the custom ICC profile (μ_2), to an equivalent one involving μ_d (= μ_1 - μ_2):

- Hypothesis: H_0: $\mu_1 - \mu_2$ = hypothesized value.
- Equivalent Hypothesis when Sample are paired
    - H_0: μ_d = hypothesized value

Sample differences (Sample 1 value – Sample 2 value) are then computed and used as the basis for testing hypotheses about μ_d. When the number of differences is large or when it is reasonable to assume that the population of differences is approximately normal, the one-sample t -Test based on the differences is the recommended test procedure. In general, the population of differences is normal if each of the two individual populations is normal. A normal probability plot or boxplot of the differences can be used to support this assumption. (Peck, Olsen, Devore, 2005, pp. 597-598).

P-Value

Peck, Olsen, and Devore defined a test of hypotheses, sometimes called a test procedure, as a method for using sample data to decide between two competing hypotheses about a population characteristic (p. 522). They described the
P-value, sometimes called the observed significance level, is a measure of inconsistency between the hypothesized value for a population characteristic and the observed sample (p. 535).

The researcher had a question: how small must the *P*-value be before the null hypothesis (H_0) should be rejected? Peck, Olsen, and Devore answered that the *P*-value depends on the significance of level α (the probability of a Type I error: the error of rejecting H_0 when H_0 is true) selected for the test. For example, suppose that the researcher set $\alpha = 0.05$. This implies that the probability of rejecting a true null hypothesis is 0.05. To obtain a test procedure with this probability of Type I error, the researcher would reject the null hypothesis if the sample result is among the most unusual 5% of all samples when H_0 is true. That is, H_0 is rejected if the computed P-value ≤ 0.05. If the researcher had selected $\alpha = 0.01$, H_0 would be rejected only if she observed a sample result so extreme that it would be among the most unusual 1% if is true (i.e., if P-value ≤ 0.01). Peck, Olsen, and Devore defined how a decision results from comparing the P-value to the chosen α (p. 536):

> H_0 should be rejected if P-value $\leq \alpha$.
> H_0 should not rejected if P-value $> \alpha$.

Following are the procedures and discussion that the researcher used to analyze the first hypothesis testing: ΔE analysis and color matching analyses including cumulative relative frequency analysis to find large color differences and to find the possible causes of the large color differences.

ΔE analysis

The researcher used ΔE distributions results from the color matching performance of the generic and the custom ICC profiles as the basis for colorimetric analysis and comparison. Specifically, the purpose for using t-Test is to determine if there are any significant differences between the color accuracy of the two ICC profiles. A t-Test in was performed between the mean of the ΔE distribution of the generic ICC profile and the mean of the ΔE distribution of the custom ICC profile. A descriptive statistical summary of the color matching experiments conducted using Microsoft Excel (2004) is shown in Figure 5.1, a histogram of the ΔE distributions from the generic ICC profile and the custom ICC profile.

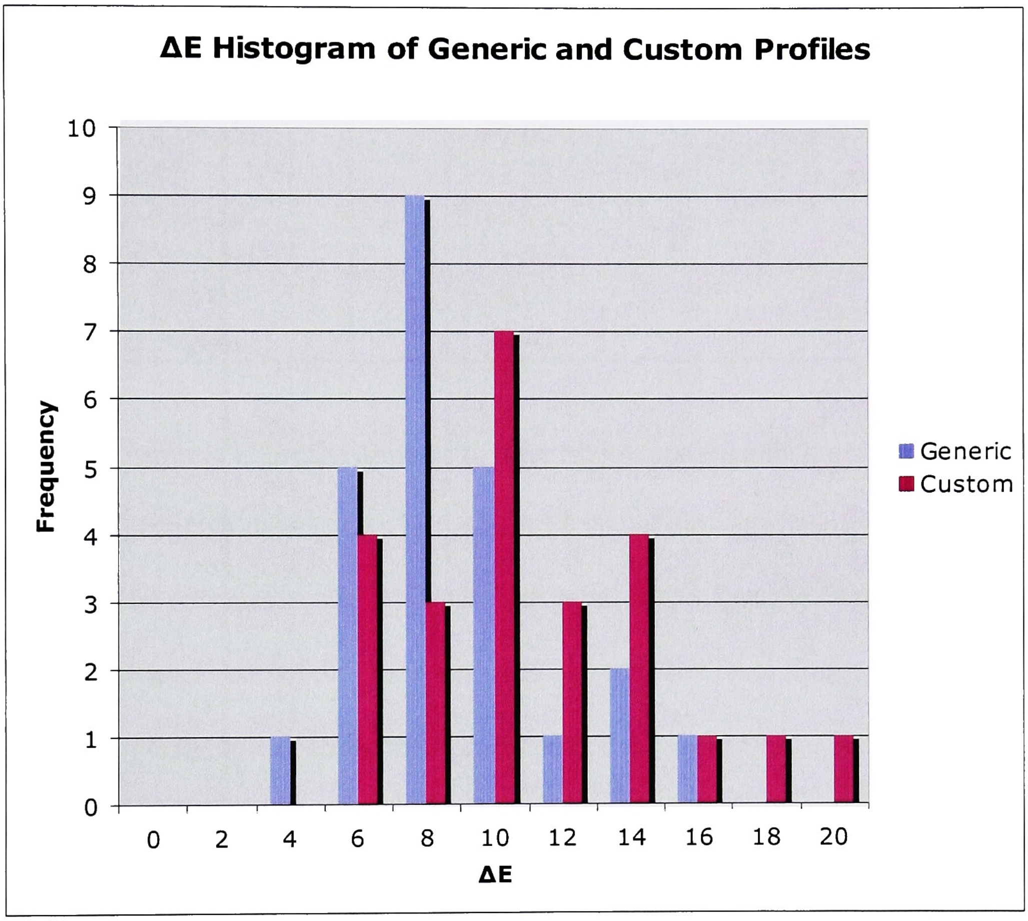


Figure 5.1. Histogram of ΔE Distributions from the Generic and the Custom Profiles

A number of conclusions shown in Table 5.1 can be stated: (1) the average of the color matching performance using the generic ICC profile is 7.75 ΔE, as opposed to 9.98 ΔE by using the custom ICC profile; and (2) the variance in ΔE distribution by the generic ICC profile is 8.06 versus 14.15 by the custom ICC profile.

Table 5.1: t-Test: Two-Sample Assuming Unequal Variances from the Generic ICC Profile and the Custom ICC Profile

ΔE	Generic	Custom
Mean	7.75	9.98
Variance	8.06	14.15
Observations	24.00	24.00
Hypothesized Mean Difference	0.00	
df (degrees of freedom)	43.00	
t Stat	-2.32	
P(T<=t) one-tail	0.01	
T Critical one-tail	1.68	
P(T<=t) two-tail	0.02	
T Critical two-tail	2.02	

The custom ICC profile appears to have higher variance than generic ICC profile, indicating that the two means, i.e., 7.75 ΔE and 9.98 ΔE are significantly different. It suggests that the two means are not equal. The result shows that the *P*-value is 0.02. With level of significance (α) at 0.05, the *P*-value is less than the level. From Peck, Olson, and Devore's acceptance or rejection decision statement, H_0 should be rejected if *P*-value $\leq\alpha$. It is $0.02 \leq 0.05$. Thus, the researcher rejected the null hypothesis and concluded that there is a difference of watercolor reproduction between a pre-media workflow using a generic ICC profile and a custom ICC profile.

Color Matching Analyses

Color matching analyses as colorimetric analyses or quantitative analyses included cumulative relative frequency, tone reproduction, gray balance, and hue reproduction. There are three purposes in colorimetric analysis between the original checker and its reproduction via two ICC profiles: (1) to find out where color differences (ΔE) exist; (2) to reduce the ΔE via profile editing; and (3) to edit the ICC profile for better color matching performance.

Cumulative Relative Frequency Analysis

The colorimetric analysis mainly focused on the use of cumulative relative frequency (CRF) of the ΔE distribution and the CRF curve of the ΔE distribution correlates with visual assessment of two pictorial color images (Chung and Shimamura, 2001). The CRF curves, shown in Figure 5.2, suggest that color reproductions from either the generic or the custom ICC profile have noticeable color differences in relation to the original Macbeth ColorChecker. The CRF curves calculate the cumulative frequencies ΔEs. The ΔEs of the values in Figure 5.2 show a noticeable in terms of matching the reference. The custom ICC profile performed worse than the generic ICC profile.

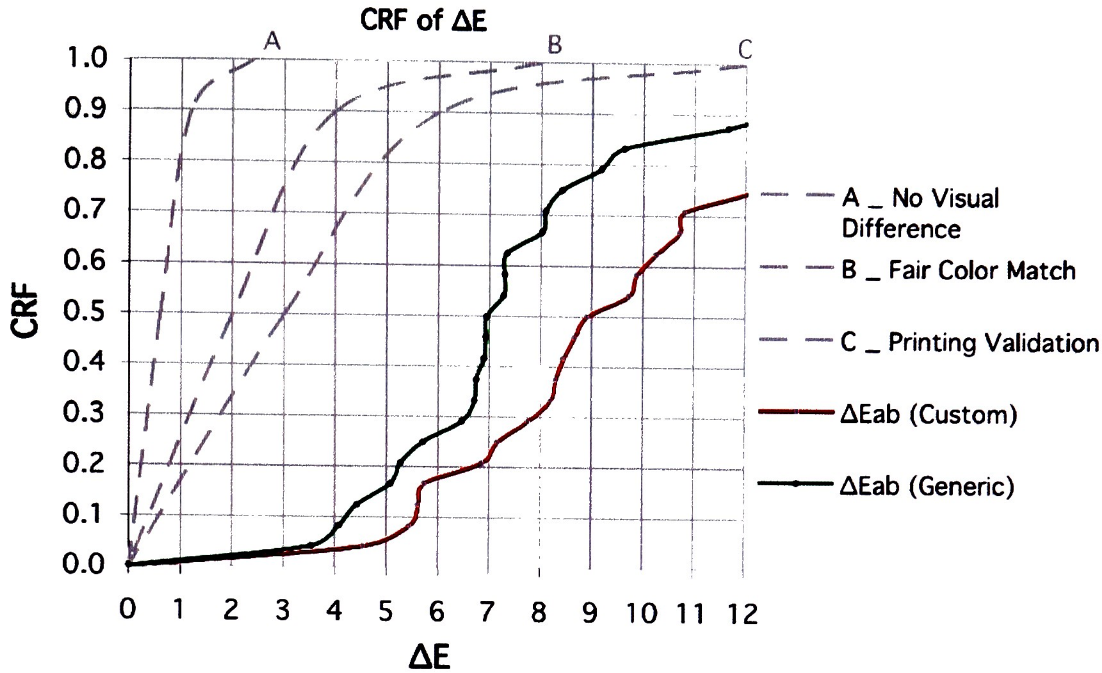


Figure 5.2. Cumulative Frequencies of ΔEs from the Generic and the Custom Profiles

Discussion

Comparison with the generic ICC profile showed use of the custom ICC profile did not improve accurate color reproduction. The data seems to suggest that mean color matching performance for the custom ICC profile is greater than the generic ICC profile.

This result from comparison between the generic ICC profile and the custom ICC profile was a surprise because the researcher expected the custom ICC profile would be necessary to do a good job and the difference in ΔE would to be small.

Possible causes of the large color differences may be from scanner profile and gamut. Discussion of how the processes involved in the large color differences for color matching evaluations caused outcome dilemmas is specified below.

Scanner Profile Dilemma

Image capture as highlighted in Figure 5.3, is the second stage in the color-managed workflow. The possible causes of the large color differences at this stage may be twofold: colors in the original are not reproducible and accuracy of the ICC profiles from the EverSmart scanner and the Epson Stylus 4000 Pro inkjet printer. In other words, are the scanner profile accurate and/or the original reproductions from and the printer reproducible or limited?

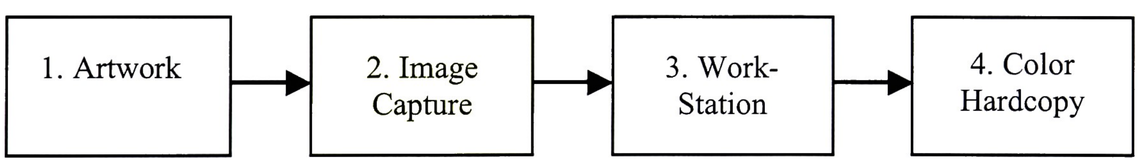


Figure 5.3. Stage 2 of Color-Managed Workflow

To check the scanner profile, Sharma (2004, p. 334) described a procedure for testing scanner profiles. The researcher and her partner, Howard Vogl: (1) scanned IT8.7/2 target and did not color manage; (2) assigned profile to be tested; (3) converted to profile, L a*b* color, with absolute colorimetric rendering intent; (4) measured La*b* values of patches and entered into Excel worksheet; (5) imported values from IT8.7/3 reference file; and (6) calculated ΔE between reference and measured sample. The researcher and her partner tried this with some sample points and got an average ΔE of 5 as reported in Appendix B.

To take it a step further, they converted the scanned target to L a*b* without assigning the EverSmart scanner profile. This simulated the condition of an unmanaged color workflow where the default space is the working space Adobe RGB. The results are: no assigned profile and measured in Photoshop was a ΔE of 21; assigned profile and measured in Photoshop was ΔE of 5. While ΔE of 5 is not perfect, it made them believe that the EverSmart scanner profile is good. However, the average of ΔE of 5 is much larger than what Sharma (2005) published in the *2005 WMU Profiling Review* (p. 3), which was ΔE of 1 for ProfileMaker 5.0.1. Kim and Vogl's result, based on repeatability, was consistent for the ΔE measured in Adobe Photoshop for the EverSmart Scanner profile. The scanner profile has an average of 5 ΔE error which significantly impacts the color matching performance of the reproduction system.

Gamut Dilemma

Colorimetric comparison between the original ColorChecker and the Epson Stylus 4000 Pro inkjet printer used ChroMix ColorThink 3.0 Pro. The researcher expected some of the 24 patches in the original ColorChecker would be outside the gamut because the printer cannot print outside of the 24 patches the original ColorChecker. However,

Figure 5.4 shows that all patches in the original ColorChecker except the white point are reproducible by the Epson printer.

The white point is not reproducible because the to-be-printed paper is not white enough and the white ink is not available for all kinds of printers. This study shows that use of profile editing tools reduces large color differences and give better performance than unedited profiles in color matching. The gamut dilemma was solved and the researcher moved to adjust the generic and custom ICC profiles.

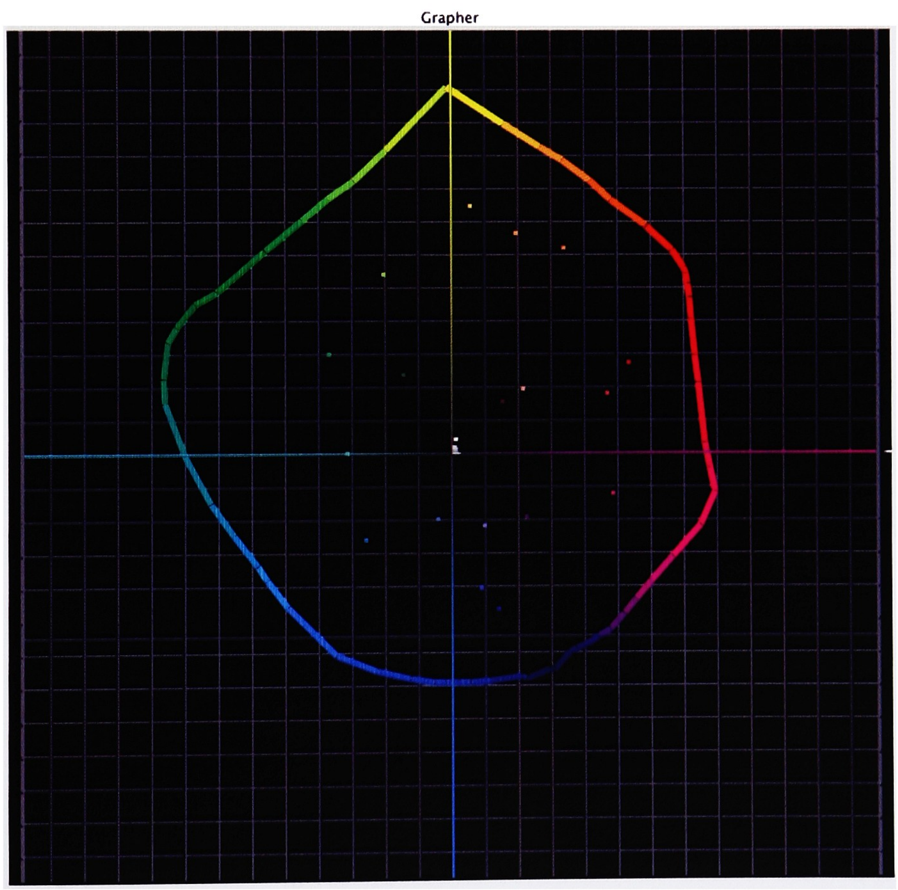


Figure 5.4. All patches are reproducible by Epson in ChroMix ColorThink 3.0 Pro

Editing Profile

Color matching analyses in editing profile are quantitative analysis and visual analysis. Referring to Pobboravsky et al. (1971), a relationship of the quantitative analysis of color matching is between a photomechanical color reproduction and an original copy (p. 155). The profile would be the custom ICC profile.

Referring to MacDonald et al. (1995), the visual analysis as the quantitative analysis is performed by a panel of human observers, like Kim and Vogl, who looked at both the original and the print and gave their opinions about the faithfulness of the reproduction (p. 255). The profile would be the generic ICC profile. Effects of how profiles editing based on the two color matching analyses could be used to solve color reproduction accuracy agreement dilemmas are also given. This work occurs in the third stage of the color-managed workflow shown in Figure 5.5.

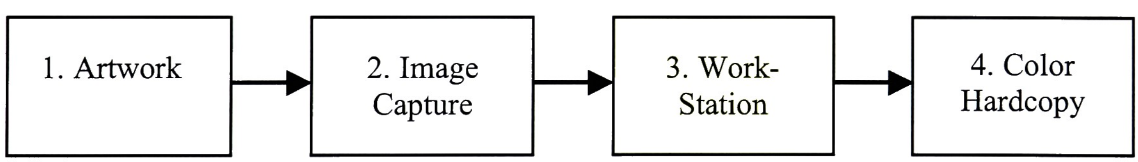


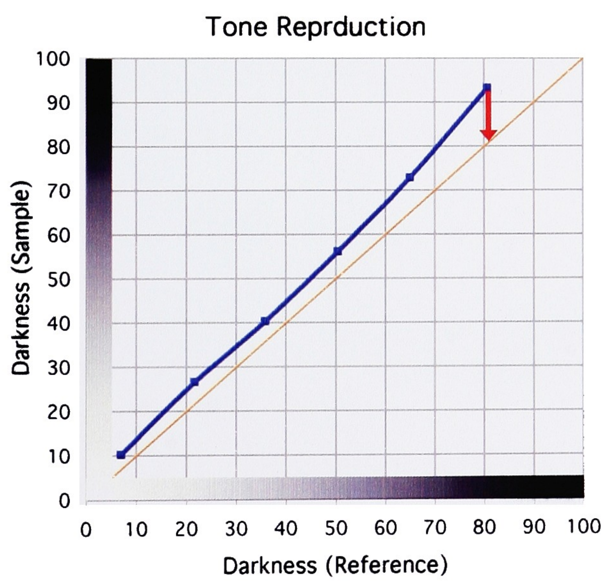
Figure 5.5. Stage 3 of Color-Managed Workflow

Editing Custom ICC Profile Based On Quantitative Analysis

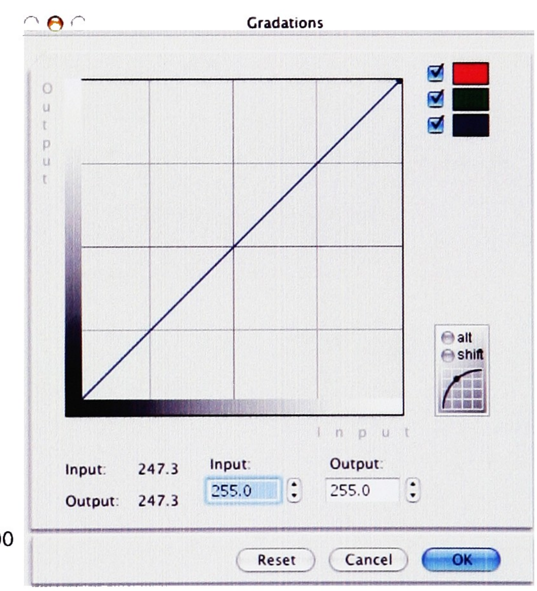
The custom ICC profile was edited based on the quantitative analysis of the gray scale portion from the Macbeth ColorChecker.

Before Edit Custom ICC Profile

In Figure 5.6, tone reproduction graph from Excel recognized that unedited custom ICC profile is darker than the original Macbeth ColorChecker; gradations tool from Profile Editor is not changed before edit.



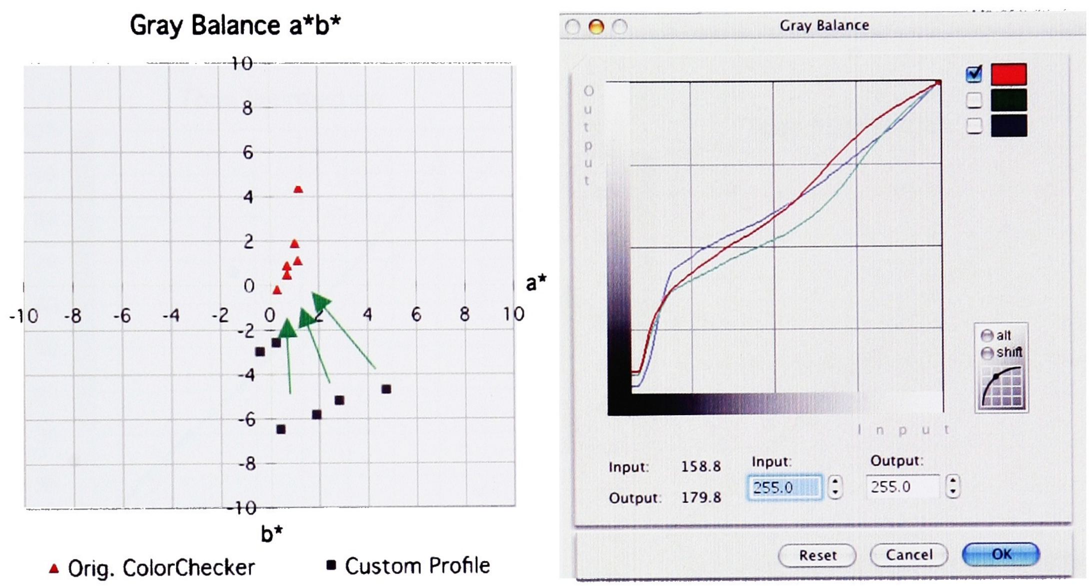
Unedited custom



Profile editing tool

Figure 5.6. Darkness of original and reproduction with Unedited Custom ICC Profile and Untouched Gradations Tool

In Figure 5.7, gray balance graph from Excel recognized that unedited custom ICC profile is bluer and redder in comparison to the original Macbeth ColorChecker in neutrals; gray balance from Profile Editor is not changed before edit.



Unedited custom

Profile editing tool
(before adjustment)

Figure 5.7. Neutrality Comparison of Unedited Custom ICC Profile and Untouched Gray Balance

After Edit Custom ICC Profile

In Figure 5.8, gray balance graph from Excel recognized that edited custom ICC profile is adjusted close to the gray scale portion of the original Macbeth Colorchecker. The profile editing improved the outcome as shown by the 45-degree straight line.

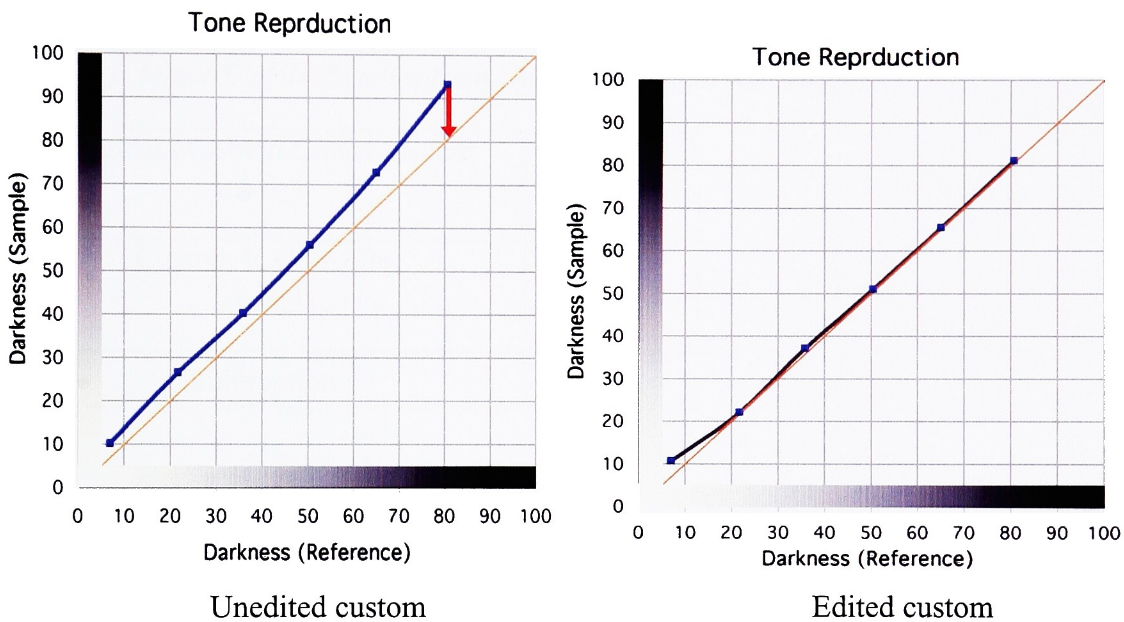


Figure 5.8. Darkness of original and reproduction with Edited Custom ICC Profile

As detailed in Appendix C, the original Macbeth ColorChecker data in tone reproduction of LAB_L of is 19.32 and the custom ICC profile data in tone reproduction of LAB_L of is 6.81 (Table 5.2). The researcher calculated an increase from 0.0 of input to 12.51 of output (Figure 5.9). It is impossible to go above 255 for the white point. The cause is no presence of white ink in any digital ink printer or to-be-printed paper itself.

Table 5.2. Max ΔE of 24 Patches from Unedited Custom ICC Profile

Original Macbeth ColorChecker LAB_L	19.32
Custom ICC Profile LAB_L	6.81
Subtraction	12.51

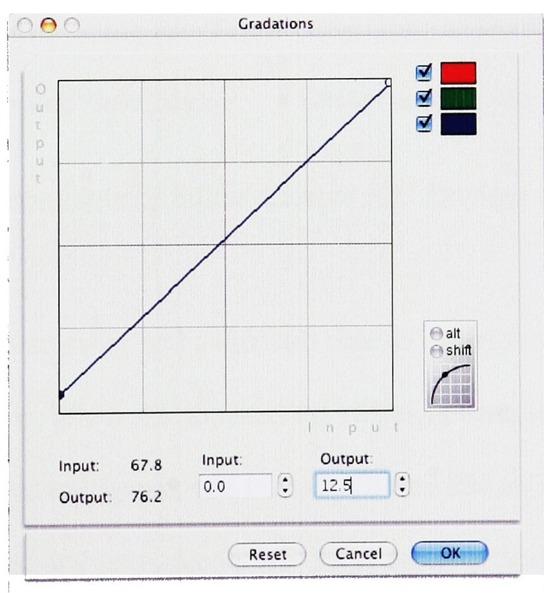


Figure 5.9. Darkness of Edited Custom ICC Profile in Gradations Tool

In Figure 5.10, gray balance graph from Excel recognized that compared to the unedited custom ICC profile, edited custom ICC profile is less blue and red. Gray balance of the reproduction from editing profile became more yellow.

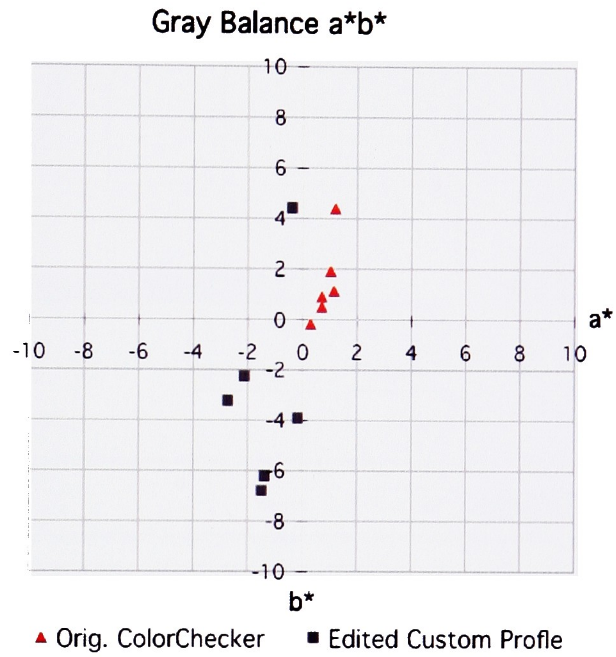


Figure 5.10. Neutrality Comparison of Edited Custom ICC Profile in Gray Balance Tool

In Figure 5.11, the researcher had a difficult time to adjust the gray balance tool from profile editing software. When she adjusted the colors in neutral; others were changed at the same time. All red, green, and blue (RGB) are 251.8 (input) / 255 (output) at the E vertical line. The researcher marked the RGB in each vertical line in Table 5.3.

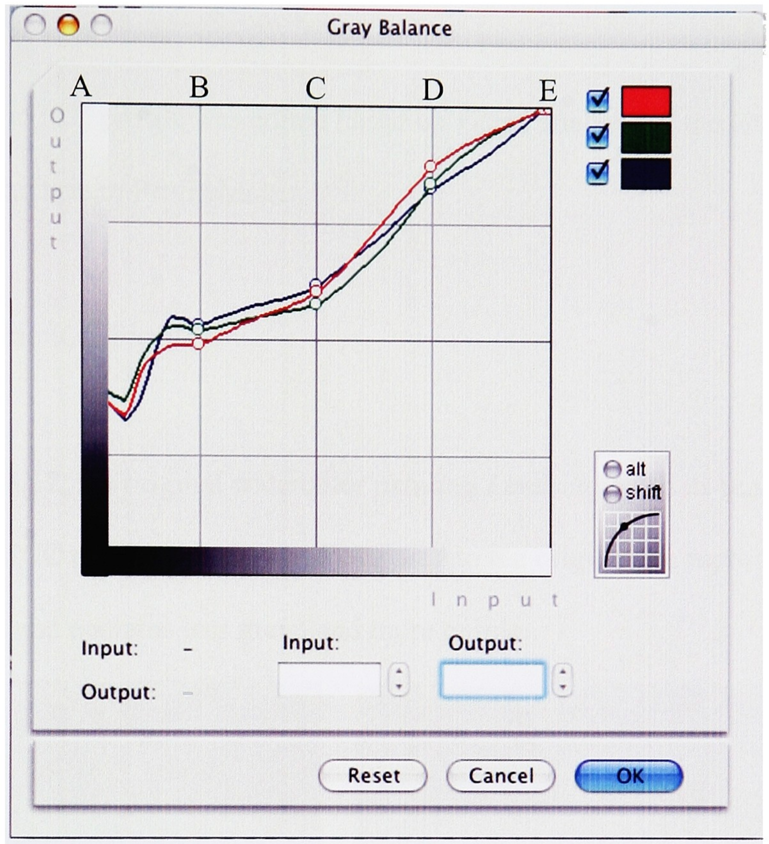


Figure 5.11. Edited Custom ICC Profile in Gray Balance Tool

Table 5.3. RGB in Data: Input / Output

	Red	Green	Blue
A (D6)	0.0/104.5	0.0/115.8	0.0/107.0
B (D4.75)	63.5/124.7	63.5/132.4	63.5/135.5
C (D3.5)	127.1/154.2	127.1/147.1	127.1/157.1
D (D2.25)	190.6/222.7	190.6/213.7	190.6/210.6
E (D1)	251.8 (input) / 255 (output)		

Editing Generic Profile Based On Visual Analysis

The generic ICC profile was edited based on visual analysis of the landscape watercolor reproduction in ProfileMaker.

Before Edit Generic ICC Profile

In Figure 5.12, the original watercolor painting *Landscape* and its reproduction using the generic ICC profile, are shown. Compared to the original the reproduction is noticeably redder and contains less green and more purple.

Figure 5.12. Original Watercolor Painting vs. Its Reproduction with Generic ICC Profile

After Edit Generic ICC Profile

Based on visual examination of the watercolor paint, the researcher and her partner had a hard time adjusting gradations and gray balance tools. They realized that every time they edited in gradations, gray balance also changed at the same time. Kim and Vogl could not determine which of the two remaining colors edited itself (Figure 5.13).

Figure 5.13. Visual Editing based on Landscape with Generic ICC Profile

Kim and Vogl edited six times, saved six ICC profiles, and printed them out for only *Landscape* watercolor painting. They agreed to choose one reproduction that happened to be the profile because they thought the fifth was the best print when compared to the other five reproductions (Figure 5.14).

Figure 5.14. Original Painting vs. Its Reproduction with Edited Generic ICC Profile

Second Hypothesis

The second hypothesis was to test if there are no significant differences in color matching performance between unedited ICC profiles and edited ICC profiles in visual analysis.

The researcher collected three watercolor paintings from RIT watercolor Professor Luvon Sheppard, and the three original paintings were reproduced. MacDonald, Morovic, and Saunders (1995) published their work with three paintings on paired comparison and suggested no single painting.

Visual analysis

Four test images of each of the three original watercolor paintings were printed using the Epson Pro Stylus 4000 resulting in a total of twelve prints each original. As identified in Table 5.4, each image was labeled on the front and top with A (Unedited Generic profile), B (Edited Generic Profile), C (Unedited Custom Profile), and D (Edited Custom Profile). A psychometric experiment was conducted in a standard viewing booth with D50 lighting and the three original paintings, L*andscape, Portrait*, and S*till Life*. The observers had no knowledge regarding the four ICC profiles used to print the images except for the labels (A, B, C, and D) on the front and top; 10 observers were selected to visually evaluate the images.

The first part of the experiment compared each of the twelve printed images with the three original watercolor paintings. The second part comprised comparing the printed images against each other, using two images: Image A and B, Image A and C, Image A and D, Image B and C, Image B and D, and Image C and D.

Table 5.4. Prints Identification

A	Unedited Generic Profile	Assigned the scanner profile and converted with the printer profile.
B	Edited Generic Profile	Edited the generic profile by using visual analysis with the only landscape painting.
C	Unedited Custom Profile	Scanned and printed to unedited custom the Epson printer.
D	Edited Custom Profile	Edited the custom profile by using quantitative analysis based on the grayscale from the original ColorChecker

As explained in Chapter 4, Methodology, this procedure for preparing and conducting the test is to demonstrate consistency among judges when testing differences in samples. The full explanation of the paired comparison test can be found in the Appendix D. The paired comparison test is to be used for testing the second hypothesis. The researcher's visual analysis is explained with reference to the original watercolor paintings, *Landscape, Portrait*, and *Still Life.*

Landscape

The four samples of the image are shown in Figure 5.15. Three out of ten were inconsistent judges. All of the judges were students of the School of Print Media at RIT with adequate technical education to recognize a good and bad reproduction. However, most of the judges spent considerable time trying to determine the best reproduction in a given pair. This meant that there was no apparent difference (*Test Targets 5.0*, 2005). The researcher chose seven consistent judges and used their results in the paired comparison performed. The landscape reproduction ranking shown in Table 5.5 was used only by the seven judges. The generic ICC profile was the best in matching the original landscape watercolor painting.

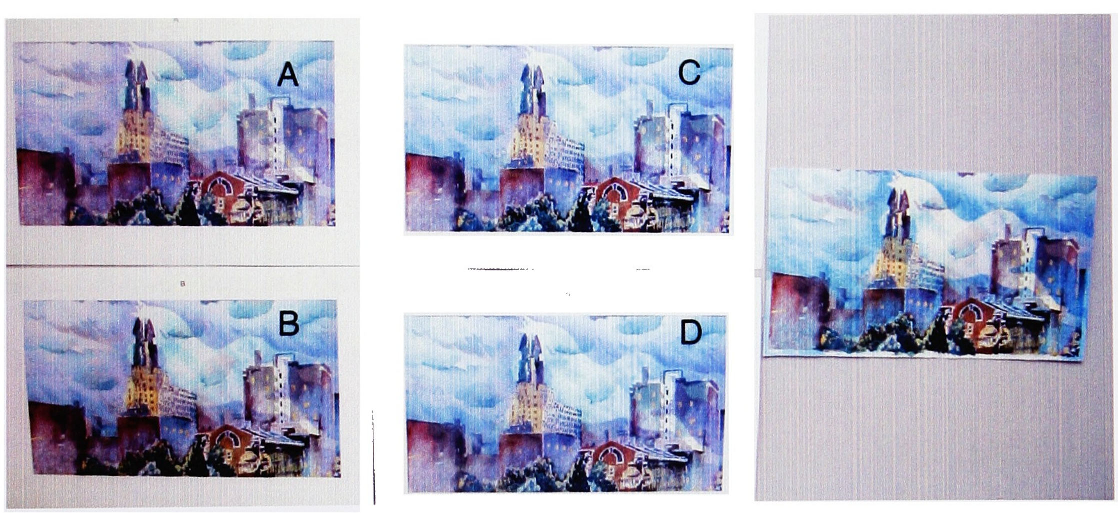


Figure 5.15. *Visual comparison of Landscape Reproduction: generic ICC profile conversion (left/top), edited generic ICC profile conversion (left/bottom), custom ICC profile conversion (right/top), and edited custom ICC profile conversion (right/bottom)*

Table 5.5. Ranking (Use only when there are 0 Triads) of Landscape Reproduction

		Description of Print Conditions
Best	A	Generic Profile
2nd	C	Custom Profile
3rd	D	Edited Custom Profile
Worst	B	Edited Generic Profile

Discussion

The test for agreement among judges calculated as the sum of squares (S) is 83. The critical value for level of significance 0.05 of agreement among judges with four prints and seven consistent judges is 217.0. The value of S (83) is less than the critical value (217.0). The researcher concluded that there is no significant agreement among consistent judges. The correlation among judges is low (0.23).

The test for real difference among prints is real difference between print A and other prints. There are no real difference among print B, C, and D.

Kim and Vogl tried their best to edit *Landscape* based on visual analysis. The researcher was surprised that the unedited generic ICC profile was still selected Best over the edited generic ICC profile.

<u>Portrait</u>

The four samples of the image are shown in Figure 5.16. All ten were consistent judges. The researcher removed three of the ten to choose the seven consistent judges and used their experiments in the paired comparison performed. The portrait reproduction ranking seen in Table 5.6 was used only by the seven judges. The custom ICC profile did the best in matching the original portrait watercolor painting.

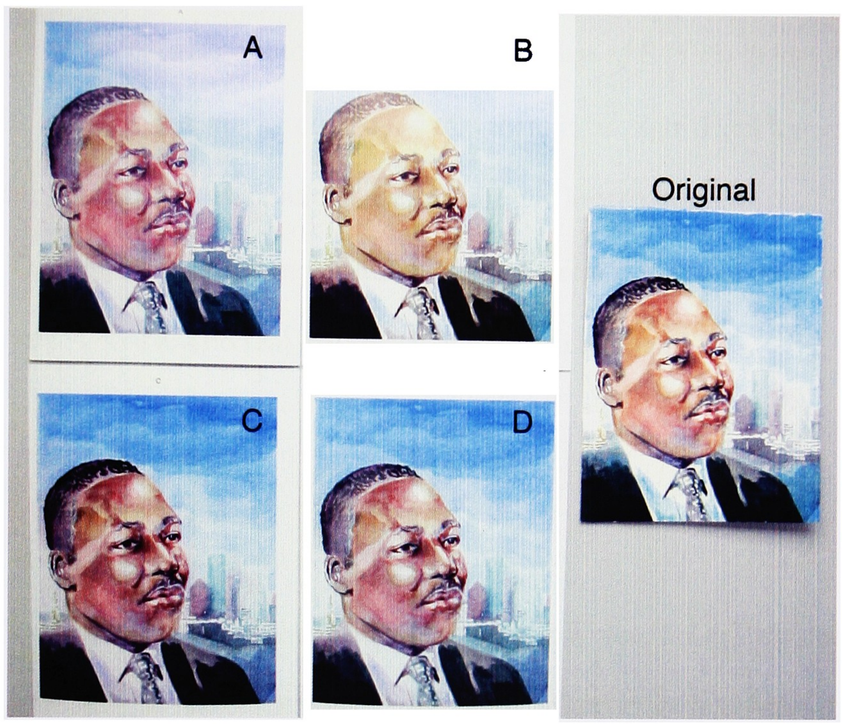


Figure 5.16. Visual comparison of Portrait Reproduction: generic ICC profile conversion (left/top), edited generic ICC profile conversion (right/top), custom ICC profile conversion (left/bottom), and edited custom ICC profile conversion (right/bottom)

Table 5.6. Ranking (Use only when there are 0 Triads) of Portrait Reproduction

		Description of Print Conditions
Best	C	Custom Profile
2nd	D	Edited Custom Profile
3rd	A	Generic Profile
Worst	B	Edited Generic Profile

Discussion

The test for agreement among judges calculated as the sum of squares (S) is 195. The critical value for level of significance 0.05 of agreement among judges with four prints and seven consistent judges is 217.0. The value of S (195) is less than the critical value (217.0). The researcher concluded that there is no significant agreement among consistent judges. The correlation among judges is low (0.76).

The test for real difference among prints is real difference between print B, C and other prints. There are no real difference among print A and D.

Still-Life

The four samples of the image are shown in Figure 5.17. Two out of ten were inconsistent judges. The researcher removed one of the eight to choose the seven consistent judges and used their experiments in the paired comparison performed. The still-life reproduction ranking show in Table 5.7 was used only by the seven judges. The edited custom ICC profile did the best in matching the original still-life watercolor painting.

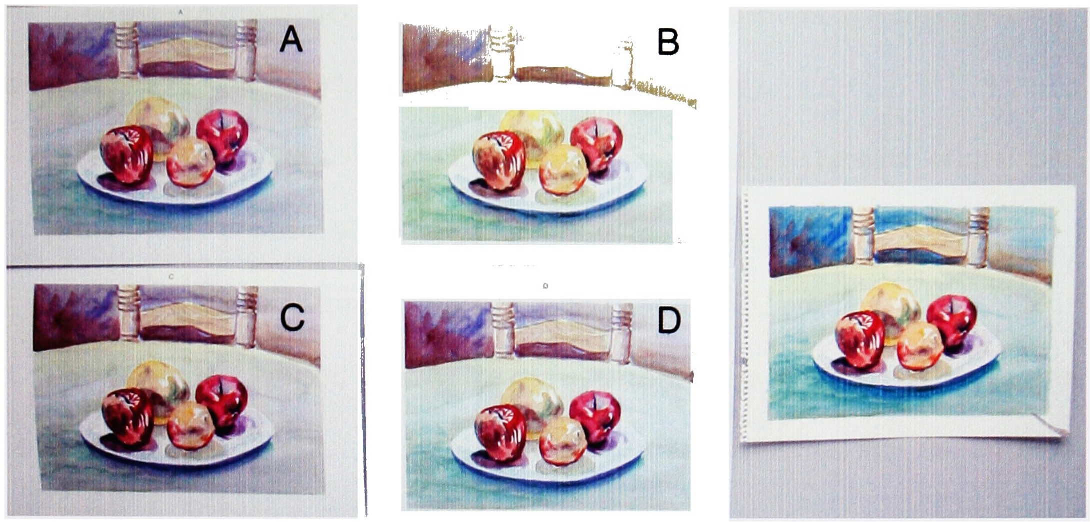


Figure 5.17. Visual comparison of Still-Life Reproduction: generic ICC profile conversion (left/top), edited generic ICC profile conversion (right/top), custom ICC profile conversion (left/bottom), and edited custom ICC profile conversion (right/bottom)

Table 5.7. Ranking (Use only when there are 0 Triads) of Still Life Reproduction

		Description of Print Conditions
Best	D	Edited Custom Profile
2nd	C	Custom Profile
3rd	A	Generic Profile
Worst	B	Edited Generic Profile

Discussion

The test for agreement among judges calculated as the sum of squares (S) is 101. The critical value for level of significance 0.05 of agreement among judges with four prints and seven consistent judges is 217.0. The value of S (101) is less than the critical value (217.0). The researcher concluded that there is no significant agreement among consistent judges. The correlation among judges is low (0.31).

The test for real difference among prints is real difference between print B and other prints. There are no real difference among print A, C, and D.

This result from comparison between the unedited ICC profiles and the edited ICC profiles was unexpected because the edited profiles were thought to be judged the best prior to the tests. The edited ICC profiles did not perform better than the unedited ICC profiles. The result that the edited ICC profiles performed worse than the unedited profiles was a surprise.

Upon replication, the researcher obtained the same results as before. The researcher and her partner tried to edit the *Landscape* painting visually using the generic ICC profile to match color performance, up to six times. However, the paired comparison test on the *Landscape* watercolor painting showed that the generic profile did the best in matching the original. Because of the visual method used on the *Landscape* printing, the edited generic ICC profile was supposed to be judged the best. But, the result showed that edited generic ICC profile performs worse than the unedited generic ICC profile.

Use of profile editing tools from GMB ProfileMaker 5, clearly demonstrated that gradations and gray balance are interdependent. If a user adjusts the gradations tool, the gray balance will change such that the user cannot see what the gray balance has changed. If the user adjusts the gray balance tool, the gradation as tone reproduction also will change such that the user cannot see what the gradations tool has changed.

The edited profile was not really effective. Profile-editing tools are not easy to use and contain software deficiencies. These issues limited the researcher's ability to achieve the desired result. Editing profile based on gray balance criteria did not produce the anticipated effect on accuracy of color imagery production of watercolor production.

Chapter 6

Summary and Conclusions

The primary goal of this thesis was for the researcher to address the problem in fine art reproduction for the need for an improved approach to achieve accurate color image reproduction. The researcher tested the color matching performance of the generic ICC profile, the custom ICC profile, and the edited ICC profiles. The researcher also used profile editing tools from GretagMacbeth ProfileMaker 5 to improve color matching performance.

Methodology Research

The researcher used the Macbeth ColorChecker to represent any watercolor paintings to be reproduced. In fact, pigments are used in the ColorChecker instead of watercolors themselves. Making one image that looks good does not guarantee that the edited profile will make other images look good (MacDonald et al., 1995).

Generic ICC Profile and Custom ICC Profile

The first null hypothesis was rejected and there was a significant color difference of watercolor reproduction between a pre-media workflow using a controlled condition generic ICC profile and using an experimental condition custom ICC profile in color matching performs once.

The custom ICC profile did not perform color matching any better than the generic ICC profile. One of the surprising conclusions shown in Table 6.1 was the difference in ΔE ranging from 8 to 10. The custom ICC profiles performed worse than the generic ICC profile. The researcher obtained the same outcome upon replications.

Table 6.1. The Two Means are Significantly Different, Not Equal, and Larger in t-Test

	Generic	**Custom**
Mean	7.75	9.98
Variance	8.06	14.15
df	43	
P-Value	0.02	

Accuracy of Scanner Profile

The different ΔE between the original watercolor painting and its reproduction is large. The accuracy of the scanner profile impacted the color matching performance as much as the printer profile. The scanner profile is responsible for the ΔE error. In fact, editing the printer profile will not fix the inaccuracy of the scanner profile.

Profile Editing

The quantitative analysis of color matching was essential for profile editing (Figure 6.1). Visual and image-based based profile editing would not work because it is difficult to reconcile visual differences into curve alteration during profile editing. Tone reproduction and gray balance are dependent factors in the profile editing process.

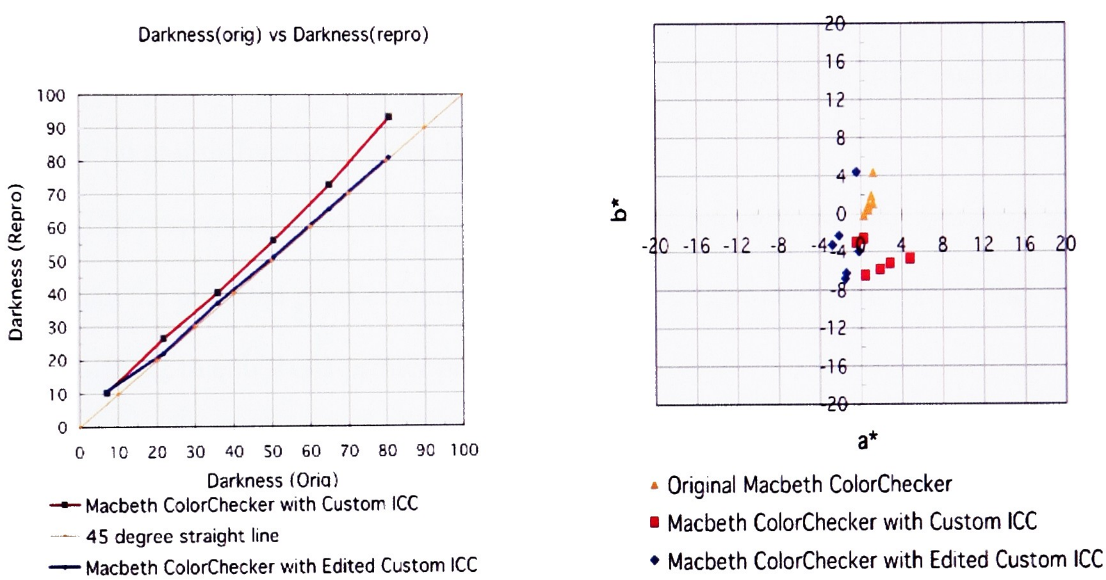


Figure 6.1. All in Each Graph of Unedited and Edited ICC Profiles

Unedited ICC Profile and Edited ICC Profile

The second null hypothesis was accepted because there is no visual significant difference in color accuracy of watercolor reproduction between a pre-media workflow using an unedited ICC profile and using an edited ICC profile.

As shown in the Table 6.2, based on the paired comparison tests of three watercolor painting with four reproductions for each painting, the researcher learned that while judges are consistent in their judging, they do not agree with one another; there is no indication that edited profiles outperform unedited ICC profile in color matching, and there are no real differences among the reproductions.

The researcher found that the edited profile did not perform color matching any better than the unedited profile. During the profile editing process, she learned that it was rather difficult to edit RGB-printer profile.

Table 6.2. Summary of the Three Paintings Paired Comparison Experiment Cases

	Landscape	**Portrait**	**Still Life**
Number Of judges participated	10	10	10
Number Of consistent judges	7	10	8
Number Of Triads from no consistent judges	ABC ACB ABD		ABD ACB
Ranking Best to Worse (total for 7 judges who are consistent and all of totals are 70)	A (Generic) C (Custom) D (Edited Custom) B (Edited Generic)	C (Custom) D (Edited Custom) A (Generic) B (Edited Generic)	D (Edited Custom) C (Custom) A (Generic) B (Edited Generic)
Best matching the original painting	Unedited Generic Profile	Unedited Custom Profile	Edited Custom Profile
Are there agreements among the consistent judges?	No	No	No
Degree of agreement (correlation among the judges)	0.23	0.76	0.31
Are there real differences among the prints?	Yes: A	Yes: B & C	Yes: B
	No: B, C, & D	No: A & D	No: A, C, & D

Chapter 7

Recommendations for Further Investigation

Regarding the methodology research, the researcher recommends that a special target with various color and neutral patches, made by watercolor, be used for quantitative analysis in the future.

Regarding the generic ICC profile and custom ICC profile research, the researcher recommends that fine art artists use generic profiles for their limited edition reproduction and follow manufacturer's recommendation for hardware and software.

Regarding the accuracy of the scanner profile research, the researcher recommends that a future researcher needs to make sure the scanner profile is verified to be accurate before the profile editing process.

Regarding the profile editing research, the researcher recommends that the following be considered: evaluations of other profile editing tools and edit CYMK-printer profiles instead of RGB-printer profiles.

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Appendices

Appendix A

Conducting a Paired Comparison Test

Conducting a Paired Comparison Test

R. Chung, RIT

1.0 Introduction

Those who study image quality know the challenges to correlate quantitative analysis results with subjective findings. CIE colorimetry, developed in 1931, has been used for quantitative analysis of color images in the graphic arts. Paired comparison is used, to some extent, to unveil subjective image evaluation results. Thurstone developed the theory of paired comparison as early as in 1927 (Engeldrum, 2000). The theory allows us to construct interval scales based on the judgments made by comparing stimuli. At RIT, we developed a number of Excel templates to implement the paired comparison analysis. This document describes the procedures for preparing and conducting the test. It also describes how data are analyzed for consistency of a judge and summary of paired comparison and ranking. In addition, test for consistency among judges and test for real difference among samples are also analyzed using five samples.

2.0 Preparing the test

2.1 Print test images based on an experimental design. These images are known as samples.

2.2 Frame the sample on a grey background. Mark each sample with a capital letter, i.e., A, B, C, etc.

2.3 Make sure that the images are linked to known treatments so that you can make inference regarding the meaning of the images in relation to data analysis.

2.4 Secure a standard viewing booth with D50 lighting.

2.5 Write down what you want the judges to do, e.g., "Which of the two images is a closer match to the reference image?" or "Which color pair has larger visual difference?"

2.6 Make sure that you have at least 10 judges for the experiment.

3.0 Conducting the test

3.1 For each judge, show each pair of images in random and in different order.

3.2 Ask the judge to mark the preferred image with an 'x' as shown in Table 1.

Table 1. Raw data.

Pair	(Choose One from the Pair)				
1	x	A	vs.		B
2	x	A	vs.		C
3	x	A	vs.		D
4	x	B	vs.		C
5	x	B	vs.		D
6		C	vs.	x	D

3.3 After all the judges have finished, then enter the data into section A of the Excel template.

4.0 Analyzing the consistency of a judge

4.1 The spreadsheet automatically counts the number of times each sample receives the mark. '0' is assigned to a sample if it receives no mark. As shown in Table 2, the sum should be '10' for five samples.

Table 2. Tally count.

Print		Count	
A		1	
B		2	
C		1	
D		2	
E		4	
	Sum =	10	<------- It should be 10

4.2 The spreadsheet automatically enters the tally count in the Section C and computes the number of triad. "0' triad indicates that the judge is consistent. '1' triad indicates that the judge has one inconsistency, etc.

4.3 In order to identify where the triad takes place, we need to construct a triad diagram, as shown in Figure 1. The first step is to place sample IDs on a piece of paper, then, draw an arrow between two samples with the arrow pointing to the preferred sample. When a circular pattern is identified, e.g., A is better than C, C is better than D, and D is better than A, this marks a triad or an inconsistency of the judge.

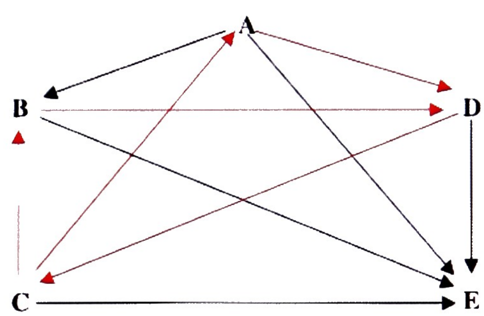


Figure 1. Triad analysis.

4.4 We will repeat the test for consistency of a judge, using the supplied spreadsheet, until all judges are analyzed.

5.0 Summarizing the test results

5.1 The spreadsheet automatically enters judges' responses into Section E of a new worksheet, called 'Analysis.'

5.2 You can select up to 7 judges to analyze their subjective responses. Pick consistent judges first before judges with triads.

5.3 Notice that averages are calculated for each of the five samples. Here, the number is proportional to its preference status. If theses averages are far apart from one another, as shown in Table 3, chances are that the judges are in agreement with each other and the sample with the highest average is the most preferred image. The opposite would also be true. In order to claim there is a significant agreement among the judges or there is significant difference among the samples, we need to continue.

Table 3. Responses of consistent judges.

The subject matter	Color Difference Pairs
Date the experiment performed	April 28, 2005
The number of judges participated	10
The number of prints	5

Print	Rank scores of all judges (add '1' to raw scores) 1	2	3	4	5	6	7	8	9	10	Ave.
A	3	3	3	4	4	4	4	2	2	2	3.10
B	3	2	2	2	2	2	2	3	3	3	2.40
C	5	5	5	5	5	5	5	5	5	5	5.00
D	1	1	1	1	1	1	1	1	1	1	1.00
E	3	4	4	3	3	3	3	4	4	4	3.50
Triad	1	0	0	0	0	0	0	0	0	0	

Print	Judges who are consistent (0 triad) 2	3	4	5	6	7	8	Ave.
A	3	3	4	4	4	4	2	3.43
B	2	2	2	2	2	2	3	2.14
C	5	5	5	5	5	5	5	5.00
D	1	1	1	1	1	1	1	1.00
E	4	4	3	3	3	3	4	3.43
	0	0	0	0	0	0	0	

The number of judges who are consistent -----> 7

The number of judges who are consistent: 7

5.4 The spreadsheet automatically summarizes the ranking order from the most preferred sample to the least preferred sample (Table 4). At the point, it is appropriate to describe what these samples represent and what can be said about these samples based on judges' responses.

Table 4. Rank ordering.

		Description of Print Conditions Color	ΔE(ab)	ΔE(00)
Best	C	Gray	5.64	5.65
2nd	A	Red/Blue	6.54	3.44
3rd	E	Blue/Red	5.61	3.09
4th	B	Green	5.25	1.91
Worst	D	Yellow	5.7	1.3

5.5 Section G of the spreadsheet tests the consistency among judges. Agreement among judges exists if the sum of squares (S), as shown in Table 5, is greater than the critical value form the supplied decision table. The correlation, R, is also calculated. If the 'R' value is higher than 0.7, it means that there is a high level of agreement among the judges. If 'R' is low, then even if the judges agree, the results are not strong enough to support any conclusion.

Table 5. Test for consistency among judges.

Print	Judges who are consistent 2	3	4	5	6	7	8	Col_9 Total for all judges	Col_10 *Average total (K37)	Col_11 Total - Average	Col_12 (T-A)²
A	3	3	4	4	4	4	2	**24**		3	9
B	2	2	2	2	2	2	3	**15**		6	36
C	5	5	5	5	5	5	5	**35**	21	14	196
D	1	1	1	1	1	1	1	**7**		-14	196
E	4	4	3	3	3	3	4	**24**		3	9
							Sum of all totals:	105		**Sum of squares (S):	446

5.6 Section H of the spreadsheet tests if there are real differences among prints at 95% confidence level.

6.0 References

6.1 Course notes on paired comparison, Professor Albert Rickmers, RIT, 1973.

6.2 Psychometric Scaling: A Toolkit for Imaging Systems Development, Peter Engeldrum, Imcotek Press, 2000.

Appendix B

Testing Scitex EverSmart Scanner Profiles

	Reference			No assigned profile, measured in Photoshop				Assigned profile measured in Photoshop			
	L*	a*	b*	L*	a*	b*	ΔE	L*	a*	b*	ΔE
A1	20.73	10.89	3.45	26	15	-3	9.29	19	13	4	2.78
A4	24.32	41.05	13.58	31	51	14	11.99	20	38	14	5.30
A8	40.6	53.53	16.27	55	59	10	16.63	39	50	13	5.07
A12	69.24	27.16	9.39	81	25	-9	21.94	70	22	3	8.25
D1	26.21	-2.82	10.99	31	-3	5	7.67	24	1	11	4.41
D4	27.09	-3.02	23.37	31	-6	30	8.25	24	0	27	5.64
D8	59.97	-2.32	69.57	66	-6	50	20.81	58	2	71	4.96
D12	79.13	-5.05	37.49	89	-5	21	19.22	80	-1	37	4.17
F1	14.62	-12.42	2.43	18	-23	1	11.20	14	-9	5	4.32
F4	17.28	-20.59	6.62	19	-43	17	24.76	14	-23	11	5.98
F8	34.13	-49.08	15.19	42	-59	11	13.34	34	-44	17	5.39
F12	68.49	-22.22	7.71	78	-26	-11	21.33	70	-19	5	4.47
H1	19.74	-8.81	-8.35	24	-13	-16	9.71	19	-6	-6	3.74
H4	21.8	-16.39	-21.39	24	-25	-27	10.51	18	-18	-18	5.34
H8	36.01	-29.04	-33.13	48	-34	-41	15.18	40	-32	-31	5.41
H12	66.64	-13.72	-21.36	78	-21	-34	18.49	70	-16	-18	5.27
J1	14.3	5.72	-15.14	18	12	-27	13.92	13	8	-13	3.39
J4	13.66	23.98	-46.76	16	32	-68	22.82	12	27	-49	4.11
J8	38.9	16.98	-32.68	53	-5	50	86.71	38	20	-38	6.18
J12	66.2	9.56	-22.42	79	-3	34	59.20	69	9	-19	4.46
L1	20.4	10.73	-2.9	26	17	-11	11.67	19	13	-2	2.81
L4	23.04	41.42	-9.01	33	54	-9	16.05	22	42	-5	4.18
L8	39.05	51.7	-10.56	54	66	-16	21.39	37	57	-13	6.18
L12	68.04	29.14	-0.66	79	26	-21	23.32	68	24	-8	8.96
						Avg	20.64			Avg	5.03

Appendix C

Quantitative Analysis

Entered three sets of data (density, CIELAB, and spectral reflectance of the 24 patches).

Data set 1 Orig. ColorChecker

Data set 2 Unedited Custom Profile

Data set 3 Unedited Generic Profile

Data set	Sample ID	SAMPLE_NAME	D_RED	D_GREEN	D_BLUE	D_VIS	LAB_L	LAB_A	LAB_B
Data set 1 Orig. ColorChecker	A-1	Dark Skin					37.3	15.44	15.7
	A-2	Light Skin					65.4	21.41	19.47
	A-3	Blue Sky					49.04	-4.21	-19.84
	A-4	Foliage					40.96	-14.44	23.76
	A-5	Blue Flower					54.37	9.77	-21.74
	A-6	Bluish Green					67.91	-31.22	0.09
	B-1	Orange					64.69	33.84	61.76
	B-2	Purplish Blue					38.76	8.79	-40.52
	B-3	Moderate Red					50.77	46.74	17.99
	B-4	Purple					30.48	22.42	-19.16
	B-5	Yellow Green					68.58	-20.54	54.05
	B-6	Orange Yellow					70.09	19.24	66.44
	C-1	Blue					28.7	13.86	-47
	C-2	Green					53.16	-36.94	30
	C-3	Red					42.36	53.46	27.36
	C-4	Yellow					77.59	5.78	74.54
	C-5	Magenta					50.51	48.62	-12.34
	C-6	Cyan					48.36	-25.95	-26.06
	D-1	White					93.01	1.19	4.4
	D-2	Neutral 8 (.23)					78.27	1.01	1.94
	D-3	Neutral 6.5 (.44)					64.09	1.14	1.15
	D-4	Neutral 5 (.70)					49.51	0.7	0.92
	D-5	Neutral 3.5 (1.05)					34.97	0.7	0.5
	D-6	Black (1.50)					19.32	0.29	-0.16
Data set 2 Unedited Custom Profile	A-1	Dark Skin					31.38	23.15	27.92
	A-2	Light Skin					60.82	21.73	12.38
	A-3	Blue Sky					43.62	-3.09	-28.46
	A-4	Foliage					37.02	-17.11	29.87
	A-5	Blue Flower					50.53	20.6	-25.59
	A-6	Bluish Green					64.94	-26.48	-3.87
	B-1	Orange					51.35	30.95	60.54
	B-2	Purplish Blue					33.49	15.4	-47.1
	B-3	Moderate Red					42.56	47.48	8.93
	B-4	Purple					26.51	41.81	-21.38
	B-5	Yellow Green					66.33	-17.15	56.04
	B-6	Orange Yellow					63.9	13.18	66.51
	C-1	Blue					18.46	20.62	-57.84
	C-2	Green					49.41	-41.19	30.83
	C-3	Red					35.2	56.18	34.97
	C-4	Yellow					73.59	3.38	77.34
	C-5	Magenta					45.94	52.19	-16.52
	C-6	Cyan					43.92	-24.35	-29.1
	D-1	White					89.81	-0.42	-2.96
	D-2	Neutral 8 (.23)					73.42	0.42	-6.46
	D-3	Neutral 6.5 (.44)					59.66	1.88	-5.82
	D-4	Neutral 5 (.70)					43.88	4.74	-4.68
	D-5	Neutral 3.5 (1.05)					27.18	2.82	-5.18
	D-6	Black (1.50)					6.81	0.25	-2.56
Data set 3 Unedited Generic Profile	A-1	Dark Skin					34.87	21.51	14.17
	A-2	Light Skin					62.38	24.55	14.33
	A-3	Blue Sky					46.98	-1.55	-26.32
	A-4	Foliage					40.49	-10.97	23.25
	A-5	Blue Flower					53.78	21.32	-23.26
	A-6	Bluish Green					66.9	-24.62	-1.64
	B-1	Orange					54.84	31.34	51.61
	B-2	Purplish Blue					38.83	14.74	-44.11
	B-3	Moderate Red					46.79	47.53	10.98
	B-4	Purple					31.85	35.19	-21.46
	B-5	Yellow Green					68.99	-15.6	52.25
	B-6	Orange Yellow					65.19	15.86	55.05
	C-1	Blue					27.59	22.3	-50.42
	C-2	Green					52.61	-37.65	26.02
	C-3	Red					40.13	55.96	31.18
	C-4	Yellow					74.78	3.33	67
	C-5	Magenta					49.79	52.52	-16.45
	C-6	Cyan					48	-18.68	-26.13
	D-1	White					90.37	-0.04	-2.34
	D-2	Neutral 8 (.23)					75.69	1.22	-5.65
	D-3	Neutral 6.5 (.44)					61.45	4.05	-4.55
	D-4	Neutral 5 (.70)					47.23	4.75	-3.58
	D-5	Neutral 3.5 (1.05)					33.41	3.73	-2.32
	D-6	Black (1.50)					9.86	0.01	-1.89

First Hypothesis: Raw Data

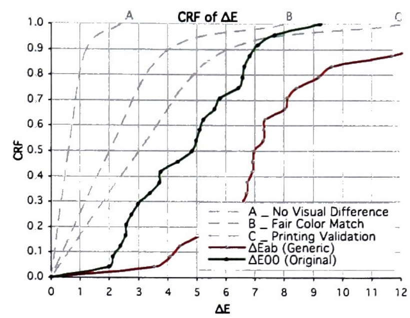
Observed ΔEs and its CRF between Generic and Custom ICC Profiles

Select the Reference: Orig. ColorChecker

Select the Sample: Unedited Generic Profile

Reference: **Orig. ColorChecker**

	Sample ID	SAMPLE_NAME	LAB_L	LAB_A	LAB_B
Orig. ColorChecker	A-1	Dark Skin	37.3	15.44	15 7
	A-2	Light Skin	65.4	21 41	19.47
	A-3	Blue Sky	49.04	-4.21	-19.84
	A-4	Foliage	40.96	-14.44	23.76
	A-5	Blue Flower	54.37	9.77	-21.74
	A-6	Bluish Green	67.91	-31.22	0.09
	B-1	Orange	64.69	33.84	61.76
	B-2	Purplish Blue	38.76	8.79	-40.52
	B-3	Moderate Red	50.77	46.74	17.99
	B-4	Purple	30.48	22.42	-19.16
	B-5	Yellow Green	68.58	-20.54	54.05
	B-6	Orange Yellow	70.09	19.24	66.44
	C-1	Blue	28.7	13.86	-47
	C-2	Green	53.16	-36.94	30
	C-3	Red	42.36	53.46	27.36
	C-4	Yellow	77 59	5.78	74.54
	C-5	Magenta	50.51	48 62	-12.34
	C-6	Cyan	48 36	-25 95	-26.06
	D-1	White	93.01	1 19	4.4
	D-2	Neutral 8 (.23)	78.27	1.01	1 94
	D-3	Neutral 6.5 (.44)	64 09	1.14	1 15
	D-4	Neutral 5 (.70)	49.51	0.7	0.92
	D-5	Neutral 3.5 (1.05)	34.97	0.7	0 5
	D-6	Black (1.50)	19 32	0 29	-0 16



Sample: **Unedited Generic Profile**

	Sample ID	SAMPLE_NAME	LAB_L	LAB_A	LAB_B	ΔL*	Δa*	Δb*	ab (Gener	00 (Origir
Unedited Generic Profile	A-1	Dark Skin	34 87	21 51	14.17	-2 43	6.07	-1.53	6 71	5 11
	A-2	Light Skin	62 38	24.55	14.33	-3.02	3 14	-5.14	6 74	5 23
	A-3	Blue Sky	46.98	-1.55	-26.32	-2.06	2.66	-6.48	7 30	3 76
	A-4	Foliage	40 49	-10.97	23.25	-0.47	3.47	-0.51	3.54	2.39
	A-5	Blue Flower	53 78	21.32	-23.26	-0 59	11.55	-1.52	11.66	7 67
	A-6	Bluish Green	66.9	-24 62	-1.64	-1.01	6.6	-1.73	6 90	3.39
	B-1	Orange	54.84	31 34	51.61	-9.85	-2.5	-10.15	14 36	9 24
	B-2	Purplish Blue	38.83	14.74	-44.11	0.07	5.95	-3.59	6 95	2 76
	B-3	Moderate Red	46 79	47 53	10.98	-3.98	0.79	-7.01	8 10	5 62
	B-4	Purple	31.85	35.19	-21.46	1.37	12.77	-2 3	13.05	5 80
	B-5	Yellow Green	68.99	-15.6	52.25	0.41	4 94	-1.8	5 27	2.57
	B-6	Orange Yellow	65.19	15 86	55.05	-4 9	-3.38	-11.39	12 85	4 98
	C-1	Blue	27.59	22.3	-50.42	-1.11	8 44	-3 42	9 17	4 35
	C-2	Green	52 61	-37 65	26.02	-0.55	-0.71	-3.98	4 08	2.00
	C-3	Red	40 13	55 96	31.18	-2.23	2.5	3 82	5.08	2.57
	C-4	Yellow	74 78	3.33	67	-2.81	-2.45	-7.54	8 41	2.98
	C-5	Magenta	49.79	52.52	-16.45	-0.72	3 9	-4.11	5.71	2.11
	C-6	Cyan	48	-18 68	-26.13	-0.36	7.27	-0.07	7.28	3 73
	D-1	White	90.37	-0 04	-2.34	-2.64	-1 23	-6 74	7.34	6 64
	D-2	Neutral 8 (.23)	75.69	1 22	-5 65	-2.58	0.21	-7.59	8.02	7 09
	D-3	Neutral 6.5 (.44)	61.45	4.05	-4 55	-2.64	2.91	-5 7	6.92	6 56
	D-4	Neutral 5 (.70)	47.23	4.75	-3.58	-2.28	4 05	-4.5	6.47	6.81
	D-5	Neutral 3.5 (1.05)	33.41	3.73	-2.32	-1.56	3 03	-2.82	4.42	4 84
	D-6	Black (1.50)	9 86	0.01	-1.89	-9 46	-0.28	-1 73	9 62	6 43
								ΔE average of 24 patches:	7.75	4.78
								max ΔE of 24 patches:	14.36	9.24

CRF		
ΔEab	ΔE00	Y-axis
0.00	0 00	0
3.54	2.00	0 04
4.08	2.11	0.08
4.42	2.39	0.13
5.08	2.57	0.17
5.27	2.57	0.21
5.71	2.76	0.25
6.47	2.98	0.29
6.71	3 39	0.33
6.74	3.73	0.38
6.90	3.76	0.42
6.92	4.35	0 46
6.95	4.84	0.50
7.28	4.98	0 54
7.30	5 11	0 58
7.34	5 23	0 63
8.02	5.62	0.67
8.10	5 80	0.71
8.41	6.43	0.75
9.17	6.56	0.79
9.62	6 64	0 83
11 66	6 81	0 88
12.85	7.09	0.92
13.05	7.67	0.96
14 36	9.24	1.00

	Unedited (ΔE)	
Bin	Generic	Custom
0	6.71496091	15.6147014
2	6.73792253	8.44670942
4	7.30134234	10.2437884
6	3.53862968	7.74497256
8	11.6645188	12.118457
10	6.89731832	6.85347357
12	14.3629732	13.7038717
14	6.94949638	10.7126747
16	8.09966666	12.2488897
18	13.0475975	19.9163601
20	5 27367993	4.52931562
	12.8517119	8.66282864
	9 17399041	16.3725624
	4.08007353	5.72834182
	5.08087591	10.7970413
	8.41131381	5 4405882
	5.7114359	7.14858028
	7.27924447	5.61384004
	7.34234976	8.18545662
	8.01926431	9.71754084
	6.92298346	8.291767
	6.46922716	8.90946126
	4.42344888	9.87121573
	9.62096149	12.7381985
Ave.	7.74895781	9.98377653
Min	3 53862968	4 52931562
Max.	14.3629732	19.9163601
Range	10.8243436	15.3870445
std dev	2.83890801	3.76160319

First Hypothesis: ΔE Analysis

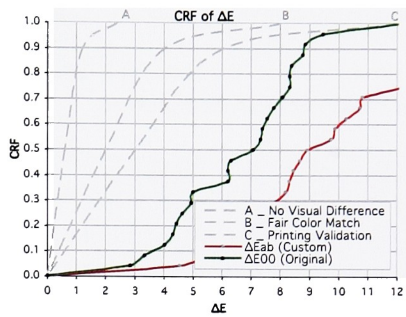
Observed ΔEs and its CRF between Generic and Custom ICC Profiles

Select the **Reference**: Orig. ColorChecker

Select the **Sample**: Unedited Custom Profile

Reference: Orig. ColorChecker

	Sample ID	SAMPLE_NAME	LAB_L	LAB_A	LAB_B
Orig. ColorChecker	A-1	Dark Skin	37.3	15.44	15.7
	A-2	Light Skin	65.4	21.41	19.47
	A-3	Blue Sky	49.04	-4.21	-19.84
	A-4	Foliage	40.96	-14.44	23.76
	A-5	Blue Flower	54.37	9.77	-21.74
	A-6	Bluish Green	67.91	-31.22	0.09
	B-1	Orange	64.69	33.84	61.76
	B-2	Purplish Blue	38.76	8.79	-40.52
	B-3	Moderate Red	50.77	46.74	17.99
	B-4	Purple	30.48	22.42	-19.16
	B-5	Yellow Green	68.58	-20.54	54.05
	B-6	Orange Yellow	70.09	19.24	66.44
	C-1	Blue	28.7	13.86	-47
	C-2	Green	53.16	-36.94	30
	C-3	Red	42.36	53.46	27.36
	C-4	Yellow	77.59	5.78	74.54
	C-5	Magenta	50.51	48.62	-12.34
	C-6	Cyan	48.36	-25.95	-26.06
	D-1	White	93.01	1.19	4.4
	D-2	Neutral 8 (.23)	78.27	1.01	1.94
	D-3	Neutral 6.5 (.44)	64.09	1.14	1.15
	D-4	Neutral 5 (.70)	49.51	0.7	0.92
	D-5	Neutral 3.5 (1.05)	34.97	0.7	0.5
	D-6	Black (1.50)	19.32	0.29	-0.16



Sample: Unedited Custom Profile

	Sample ID	SAMPLE_NAME	LAB_L	LAB_A	LAB_B	ΔL*	Δa*	Δb*	:ab (Custo	:00 (Origin	CRF ΔEab	CRF ΔE00	CRF Y-axis
											0.00	0.00	0
Unedited Custom Profile	A-1	Dark Skin	31.38	23.15	27.92	-5.92	7.71	12.22	15.61	8.07	4.53	2.84	0.04
	A-2	Light Skin	60.82	21.73	12.38	-4.58	0.32	-7.09	8.45	6.20	5.44	3.33	0.08
	A-3	Blue Sky	43.62	-3.09	-28.46	-5.42	1.12	-8.62	10.24	6.31	5.61	4.03	0.13
	A-4	Foliage	37.02	-17.11	29.87	-3.94	-2.67	6.11	7.74	4.42	5.73	4.31	0.17
	A-5	Blue Flower	50.53	20.6	-25.59	-3.84	10.83	-3.85	12.12	7.55	6.85	4.42	0.21
	A-6	Bluish Green	64.94	-26.48	-3.87	-2.97	4.74	-3.96	6.85	4.31	7.15	4.64	0.25
	B-1	Orange	51.35	30.95	60.54	-13.34	-2.89	-1.22	13.70	12.15	7.74	4.94	0.29
	B-2	Purplish Blue	33.49	15.4	-47.1	-5.27	6.61	-6.58	10.71	4.99	8.19	4.99	0.33
	B-3	Moderate Red	42.56	47.48	8.93	-8.21	0.74	-9.06	12.25	9.46	8.29	6.20	0.38
	B-4	Purple	26.51	41.81	-21.38	-3.97	19.39	-2.22	19.92	8.77	8.45	6.20	0.42
	B-5	Yellow Green	66.33	-17.15	56.04	-2.25	3.39	1.99	4.53	2.84	8.66	6.31	0.46
	B-6	Orange Yellow	63.9	13.18	66.51	-6.19	-6.06	0.07	8.66	6.20	8.91	7.05	0.50
	C-1	Blue	18.46	20.62	-57.84	-10.24	6.76	-10.84	16.37	7.78	9.72	7.32	0.54
	C-2	Green	49.41	-41.19	30.83	-3.75	-4.25	0.83	5.73	4.03	9.87	7.39	0.58
	C-3	Red	35.2	56.18	34.97	-7.16	2.72	7.61	10.80	7.05	10.24	7.55	0.63
	C-4	Yellow	73.59	3.38	77.34	-4	-2.4	2.8	5.44	3.33	10.71	7.78	0.67
	C-5	Magenta	45.94	52.19	-16.52	-4.57	3.57	-4.18	7.15	4.94	10.80	8.07	0.71
	C-6	Cyan	43.92	-24.35	-29.1	-4.44	1.6	-3.04	5.61	4.64	12.12	8.33	0.75
	D-1	White	89.81	-0.42	-2.96	-3.2	-1.61	-7.36	8.19	7.39	12.25	8.33	0.79
	D-2	Neutral 8 (.23)	73.42	0.42	-6.46	-4.85	-0.59	-8.4	9.72	8.33	12.74	8.38	0.83
	D-3	Neutral 6.5 (.44)	59.66	1.88	-5.82	-4.43	0.74	-6.97	8.29	7.32	13.70	8.77	0.88
	D-4	Neutral 5 (.70)	43.88	4.74	-4.68	-5.63	4.04	-5.6	8.91	8.85	15.61	8.85	0.92
	D-5	Neutral 3.5 (1.05)	27.18	2.82	-5.18	-7.79	2.12	-5.68	9.87	8.33	16.37	9.46	0.96
	D-6	Black (1.50)	6.81	0.25	-2.56	-12.51	-0.04	-2.4	12.74	8.38	19.92	12.15	1.00
								ΔE average of 24 patches:	9.98	6.74			
								max ΔE of 24 patches:	19.92	12.15			

Unedited (ΔE)

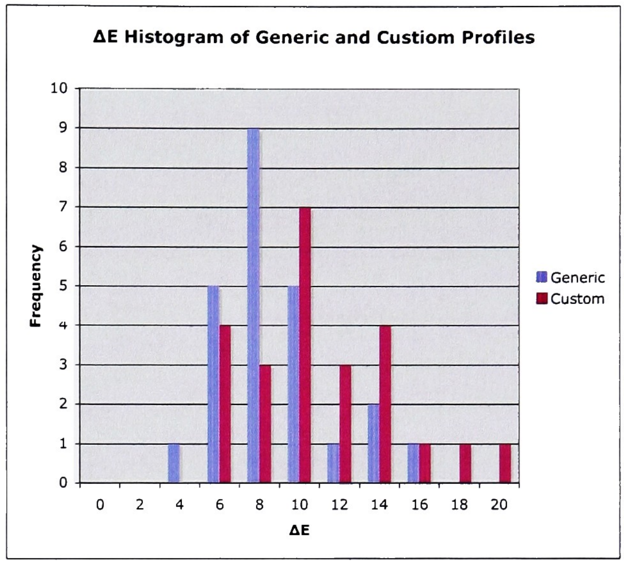
Bin	Generic	Custom
0	6.71496091	15.6147014
2	6.73792253	8.44670942
4	7.30134234	10.2437884
6	3.53862968	7.74497256
8	11.6645188	12.118457
10	6.89731832	6.85347357
12	14.3629732	13.7038717
14	6.94949638	10.7126747
16	8.09966666	12.2488897
18	13.0475975	19.9163601
20	5.27367993	4.52931562
	12.8517119	8.66282864
	9.17399041	16.3725624
	4.08007353	5.72834182
	5.08087591	10.7970413
	8.41131381	5.4405882
	5.7114359	7.14858028
	7.27924447	5.61384004
	7.34234976	8.18545662
	8.01926431	9.71754084
	6.92298346	8.291767
	6.46922716	8.90946126
	4.42344888	9.87121573
	9.62096149	12.7381985
Ave	7.74895781	9.98377653
Min	3.53862968	4.52931562
Max.	14.3629732	19.9163601
Range	10.8243436	15.3870445
std dev.	2.83890801	3.76160319

First Hypothesis: ΔE Analysis (2)

Unedited (ΔE)

Bin	Generic	Custom
0	6.714960908	15.6147014
2	6.737922528	8.44670942
4	7.301342342	10.2437884
6	3.538629678	7.74497256
8	11.66451885	12.118457
10	6.897318319	6.85347357
12	14.36297323	13.7038717
14	6.949496385	10.7126747
16	8.09966666	12.2488897
18	13.04759748	19.9163601
20	5.27367993	4.52931562
	12.85171195	8.66282864
	9.173990408	16.3725624
	4.080073529	5.72834182
	5.080875909	10.7970413
	8.411313809	5.4405882
	5.711435897	7.14858028
	7.279244466	5.61384004
	7.34234976	8.18545662
	8.019264305	9.71754084
	6.922983461	8.291767
	6.469227156	8.90946126
	4.423448881	9.87121573
	9.62096149	12.7381985
Ave.	7.748957805	9.98377653
Min.	3.538629678	4.52931562
Max.	14.36297323	19.9163601
Range	10.82434355	15.3870445
std dev.	2.838908014	3.76160319
Variance	8.059398709	14.1496586

Bin	*Generic*	*Custom*
0	0	0
2	0	0
4	1	0
6	5	4
8	9	3
10	5	7
12	1	3
14	2	4
16	1	1
18	0	1
20	0	1



t-Test: Two-Sample Assuming Unequal Variances (alpha risk of 0.05)

	Generic	Custom
Mean	7.75	9.98
Variance	8.06	14.15
Observations	24.00	24.00
Hypothesized Mean	0.00	
df	43.00	
t Stat	-2.32	
P(T<=t) one-tail	0.01	
t Critical one-tail	1.68	
P(T<=t) two-tail	0.02	
t Critical two-tail	2.02	

First Hypothesis: ΔE Histogram

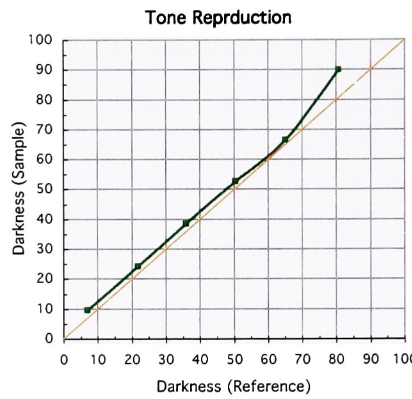
Shown Tone Reprduction in Terms between Original vs. Custom ICC Profile

Orig. ColorChecker

Unedited Generic Profile

Reference: **Orig. ColorChecker**

	Sample ID	SAMPLE_NAME	LAB_L	LAB_A	LAB_B	Darkness	Density
Orig. ColorChecker	A-1	Dark Skin	37.3	15.44	15.7	62.70	
	A-2	Light Skin	65.4	21.41	19.47	34.60	
	A-3	Blue Sky	49.04	-4.21	-19.84	50.96	
	A-4	Foliage	40.96	-14.44	23.76	59.04	
	A-5	Blue Flower	54.37	9.77	-21.74	45.63	
	A-6	Bluish Green	67.91	-31.22	0.09	32.09	
	B-1	Orange	64.69	33.84	61.76	35.31	
	B-2	Purplish Blue	38.76	8.79	-40.52	61.24	
	B-3	Moderate Red	50.77	46.74	17.99	49.23	
	B-4	Purple	30.48	22.42	-19.16	69.52	
	B-5	Yellow Green	68.58	-20.54	54.05	31.42	
	B-6	Orange Yellow	70.09	19.24	66.44	29.91	
	C-1	Blue	28.7	13.86	-47	71.30	
	C-2	Green	53.16	-36.94	30	46.84	
	C-3	Red	42.36	53.46	27.36	57.64	
	C-4	Yellow	77.59	5.78	74.54	22.41	
	C-5	Magenta	50.51	48.62	-12.34	49.49	
	C-6	Cyan	48.36	-25.95	-26.06	51.64	
	D-1	White	93.01	1.19	4.4	6.99	#N/A
	D-2	Neutral 8 (.23)	78.27	1.01	1.94	21.73	#N/A
	D-3	Neutral 6.5 (.44)	64.09	1.14	1.15	35.91	#N/A
	D-4	Neutral 5 (.70)	49.51	0.7	0.92	50.49	#N/A
	D-5	Neutral 3.5 (1.05)	34.97	0.7	0.5	65.03	#N/A
	D-6	Black (1.50)	19.32	0.29	-0.16	80.68	#N/A



Sample: **Unedited Generic Profile**

	Sample ID	SAMPLE_NAME	LAB_L	LAB_A	LAB_B	Darkness	Density
Unedited Generic Profile	A-1	Dark Skin	34.87	21.51	14.17	65.13	
	A-2	Light Skin	62.38	24.55	14.33	37.62	
	A-3	Blue Sky	46.98	-1.55	-26.32	53.02	
	A-4	Foliage	40.49	-10.97	23.25	59.51	
	A-5	Blue Flower	53.78	21.32	-23.26	46.22	
	A-6	Bluish Green	66.9	-24.62	-1.64	33.10	
	B-1	Orange	54.84	31.34	51.61	45.16	
	B-2	Purplish Blue	38.83	14.74	-44.11	61.17	
	B-3	Moderate Red	46.79	47.53	10.98	53.21	
	B-4	Purple	31.85	35.19	-21.46	68.15	
	B-5	Yellow Green	68.99	-15.6	52.25	31.01	
	B-6	Orange Yellow	65.19	15.86	55.05	34.81	
	C-1	Blue	27.59	22.3	-50.42	72.41	
	C-2	Green	52.61	-37.65	26.02	47.39	
	C-3	Red	40.13	55.96	31.18	59.87	
	C-4	Yellow	74.78	3.33	67	25.22	
	C-5	Magenta	49.79	52.52	-16.45	50.21	
	C-6	Cyan	48	-18.68	-26.13	52.00	
	D-1	White	90.37	-0.04	-2.34	9.63	#N/A
	D-2	Neutral 8 (.23)	75.69	1.22	-5.65	24.31	#N/A
	D-3	Neutral 6.5 (.44)	61.45	4.05	-4.55	38.55	#N/A
	D-4	Neutral 5 (.70)	47.23	4.75	-3.58	52.77	#N/A
	D-5	Neutral 3.5 (1.05)	33.41	3.73	-2.32	66.59	#N/A
	D-6	Black (1.50)	9.86	0.01	-1.89	90.14	#N/A

First Hypothesis: Tone Reproduction

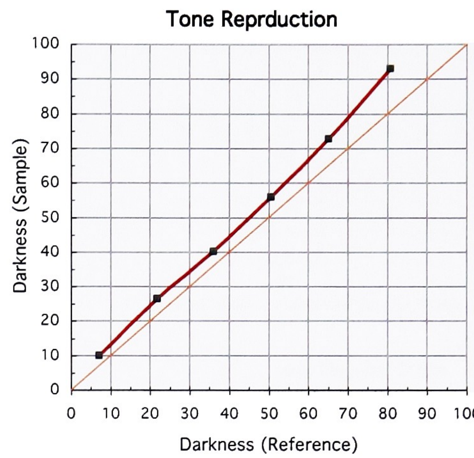
Show tone reprduction in terms of original vs. reproduction between the reference and the sample.

Select the Reference: Orig. ColorChecker

Select the Sample: Unedited Custom Profile

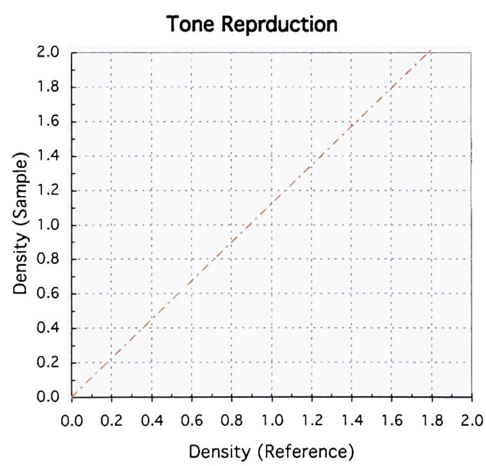
Reference: **Orig. ColorChecker**

	Sample ID	SAMPLE_NAME	LAB_L	LAB_A	LAB_B	Darkness	Density
Orig. ColorChecker	A-1	Dark Skin	37.3	15.44	15.7	62.70	
	A-2	Light Skin	65.4	21.41	19.47	34.60	
	A-3	Blue Sky	49.04	-4.21	-19.84	50.96	
	A-4	Foliage	40.96	-14.44	23.76	59.04	
	A-5	Blue Flower	54.37	9.77	-21.74	45.63	
	A-6	Bluish Green	67.91	-31.22	0.09	32.09	
	B-1	Orange	64.69	33.84	61.76	35.31	
	B-2	Purplish Blue	38.76	8.79	-40.52	61.24	
	B-3	Moderate Red	50.77	46.74	17.99	49.23	
	B-4	Purple	30.48	22.42	-19.16	69.52	
	B-5	Yellow Green	68.58	-20.54	54.05	31.42	
	B-6	Orange Yellow	70.09	19.24	66.44	29.91	
	C-1	Blue	28.7	13.86	-47	71.30	
	C-2	Green	53.16	-36.94	30	46.84	
	C-3	Red	42.36	53.46	27.36	57.64	
	C-4	Yellow	77.59	5.78	74.54	22.41	
	C-5	Magenta	50.51	48.62	-12.34	49.49	
	C-6	Cyan	48.36	-25.95	-26.06	51.64	
	D-1	White	93.01	1.19	4.4	6.99	#N/A
	D-2	Neutral 8 (.23)	78.27	1.01	1.94	21.73	#N/A
	D-3	Neutral 6.5 (.44)	64.09	1.14	1.15	35.91	#N/A
	D-4	Neutral 5 (.70)	49.51	0.7	0.92	50.49	#N/A
	D-5	Neutral 3.5 (1.05)	34.97	0.7	0.5	65.03	#N/A
	D-6	Black (1.50)	19.32	0.29	-0.16	80.68	#N/A



Sample: **Unedited Custom Profile**

	Sample ID	SAMPLE_NAME	LAB_L	LAB_A	LAB_B	Darkness	Density
Unedited Custom Profile	A-1	Dark Skin	31.38	23.15	27.92	68.62	
	A-2	Light Skin	60.82	21.73	12.38	39.18	
	A-3	Blue Sky	43.62	-3.09	-28.46	56.38	
	A-4	Foliage	37.02	-17.11	29.87	62.98	
	A-5	Blue Flower	50.53	20.6	-25.59	49.47	
	A-6	Bluish Green	64.94	-26.48	-3.87	35.06	
	B-1	Orange	51.35	30.95	60.54	48.65	
	B-2	Purplish Blue	33.49	15.4	-47.1	66.51	
	B-3	Moderate Red	42.56	47.48	8.93	57.44	
	B-4	Purple	26.51	41.81	-21.38	73.49	
	B-5	Yellow Green	66.33	-17.15	56.04	33.67	
	B-6	Orange Yellow	63.9	13.18	66.51	36.10	
	C-1	Blue	18.46	20.62	-57.84	81.54	
	C-2	Green	49.41	-41.19	30.83	50.59	
	C-3	Red	35.2	56.18	34.97	64.80	
	C-4	Yellow	73.59	3.38	77.34	26.41	
	C-5	Magenta	45.94	52.19	-16.52	54.06	
	C-6	Cyan	43.92	-24.35	-29.1	56.08	
	D-1	White	89.81	-0.42	-2.96	10.19	#N/A
	D-2	Neutral 8 (.23)	73.42	0.42	-6.46	26.58	#N/A
	D-3	Neutral 6.5 (.44)	59.66	1.88	-5.82	40.34	#N/A
	D-4	Neutral 5 (.70)	43.88	4.74	-4.68	56.12	#N/A
	D-5	Neutral 3.5 (1.05)	27.18	2.82	-5.18	72.82	#N/A
	D-6	Black (1.50)	6.81	0.25	-2.56	93.19	#N/A



4. Tone Reproduction

Compare Colorimetric Differences of Neutrals a*b* Diagram and L*C* Plots.

Orig. ColorChecker

Unedited Custom Profile

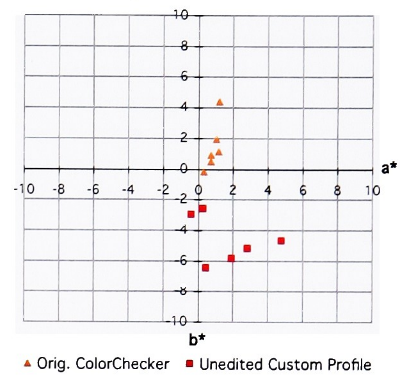
Reference: **Orig. ColorChecker**

	Sample ID	SAMPLE_NAME	LAB_L	LAB_A	LAB_B	C*	Darkness
Orig. ColorChecker	A-1	Dark Skin	37.3	15.44	15.7	22.02	62.70
	A-2	Light Skin	65.4	21.41	19.47	28.94	34.60
	A-3	Blue Sky	49.04	-4.21	-19.84	20.28	50.96
	A-4	Foliage	40.96	-14.44	23.76	27.80	59.04
	A-5	Blue Flower	54.37	9.77	-21.74	23.83	45.63
	A-6	Bluish Green	67.91	-31.22	0.09	31.22	32.09
	B-1	Orange	64.69	33.84	61.76	70.42	35.31
	B-2	Purplish Blue	38.76	8.79	-40.52	41.46	61.24
	B-3	Moderate Red	50.77	46.74	17.99	50.08	49.23
	B-4	Purple	30.48	22.42	-19.16	29.49	69.52
	B-5	Yellow Green	68.58	-20.54	54.05	57.82	31.42
	B-6	Orange Yellow	70.09	19.24	66.44	69.17	29.91
	C-1	Blue	28.7	13.86	-47	49.00	71.30
	C-2	Green	53.16	-36.94	30	47.59	46.84
	C-3	Red	42.36	53.46	27.36	60.05	57.64
	C-4	Yellow	77.59	5.78	74.54	74.76	22.41
	C-5	Magenta	50.51	48.62	-12.34	50.16	49.49
	C-6	Cyan	48.36	-25.95	-26.06	36.78	51.64
	D-1	White	93.01	1.19	4.4	4.56	6.99
	D-2	Neutral 8 (.23)	78.27	1.01	1.94	2.19	21.73
	D-3	Neutral 6.5 (.44)	64.09	1.14	1.15	1.62	35.91
	D-4	Neutral 5 (.70)	49.51	0.7	0.92	1.16	50.49
	D-5	Neutral 3.5 (1.05)	34.97	0.7	0.5	0.86	65.03
	D-6	Black (1.50)	19.32	0.29	-0 16	0.33	80.68
					GS (C* Sum) =	10.71	

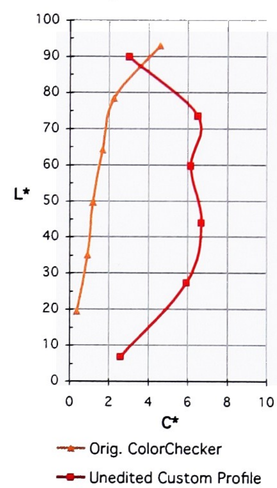
Sample: **Unedited Custom Profile**

	Sample ID	SAMPLE_NAME	LAB_L	LAB_A	LAB_B	C*	Darkness	ΔEab	ΔE00
Unedited Custom Profile	A-1	Dark Skin	31.38	23.15	27.92	36.27	68.62		
	A-2	Light Skin	60.82	21.73	12.38	25.01	39.18		
	A-3	Blue Sky	43.62	-3.09	-28.46	28.63	56.38		
	A-4	Foliage	37.02	-17.11	29.87	34.42	62.98		
	A-5	Blue Flower	50.53	20.6	-25.59	32.85	49.47		
	A-6	Bluish Green	64.94	-26.48	-3.87	26.76	35.06		
	B-1	Orange	51.35	30.95	60.54	67.99	48.65		
	B-2	Purplish Blue	33.49	15.4	-47.1	49.55	66.51		
	B-3	Moderate Red	42.56	47.48	8.93	48.31	57.44		
	B-4	Purple	26.51	41.81	-21.38	46.96	73.49		
	B-5	Yellow Green	66.33	-17.15	56.04	58.61	33.67		
	B-6	Orange Yellow	63.9	13.18	66.51	67.80	36.10		
	C-1	Blue	18.46	20.62	-57.84	61.41	81.54		
	C-2	Green	49.41	-41.19	30.83	51.45	50.59		
	C-3	Red	35.2	56.18	34.97	66.17	64.80		
	C-4	Yellow	73.59	3.38	77.34	77.41	26.41		
	C-5	Magenta	45.94	52.19	-16.52	54.74	54.06		
	C-6	Cyan	43.92	-24.35	-29.1	37.94	56.08		
	D-1	White	89.81	-0.42	-2.96	2.99	10.19	8.19	7.39
	D-2	Neutral 8 (.23)	73.42	0.42	-6.46	6.47	26.58	9.72	8.33
	D-3	Neutral 6.5 (.44)	59.66	1.88	-5.82	6.12	40.34	8.29	7.32
	D-4	Neutral 5 (.70)	43.88	4.74	-4.68	6.66	56.12	8.91	8.85
	D-5	Neutral 3.5 (1.05)	27.18	2.82	-5.18	5.90	72.82	9.87	8.33
	D-6	Black (1.50)	6.81	0.25	-2.56	2.57	93.19	12.74	8.38
							ΔE average of neutrals:	9.62	8.10
							max ΔE of neutrals:	12.74	8.85
					GS (C* Sum) =	30.71			

Gray Balance a*b* Plot



Gray Blanace L*C* Plot



First Hypothesis: Gray Balance (2)

Compare Colorimetric Differences of Neutrals a*b* Diagram and L*C* Plots.

Orig. ColorChecker

Unedited Generic Profile

Reference: Orig. ColorChecker

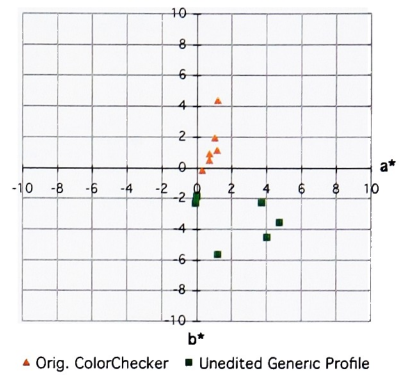
	Sample ID	SAMPLE_NAME	LAB_L	LAB_A	LAB_B	C*	Darkness
Orig. ColorChecker	A-1	Dark Skin	37.3	15.44	15.7	22.02	62.70
	A-2	Light Skin	65.4	21.41	19.47	28.94	34.60
	A-3	Blue Sky	49.04	-4.21	-19.84	20.28	50.96
	A-4	Foliage	40.96	-14.44	23.76	27.80	59.04
	A-5	Blue Flower	54.37	9.77	-21.74	23.83	45.63
	A-6	Bluish Green	67.91	-31.22	0.09	31.22	32.09
	B-1	Orange	64.69	33.84	61.76	70.42	35.31
	B-2	Purplish Blue	38.76	8.79	-40.52	41.46	61.24
	B-3	Moderate Red	50.77	46.74	17.99	50.08	49.23
	B-4	Purple	30.48	22.42	-19.16	29.49	69.52
	B-5	Yellow Green	68.58	-20.54	54.05	57.82	31.42
	B-6	Orange Yellow	70.09	19.24	66.44	69.17	29.91
	C-1	Blue	28.7	13.86	-47	49.00	71.30
	C-2	Green	53.16	-36.94	30	47.59	46.84
	C-3	Red	42.36	53.46	27.36	60.05	57.64
	C-4	Yellow	77.59	5.78	74.54	74.76	22.41
	C-5	Magenta	50.51	48.62	-12.34	50.16	49.49
	C-6	Cyan	48.36	-25.95	-26.06	36.78	51.64
	D-1	White	93.01	1.19	4.4	4.56	6.99
	D-2	Neutral 8 (.23)	78.27	1.01	1.94	2.19	21.73
	D-3	Neutral 6.5 (.44)	64.09	1.14	1.15	1.62	35.91
	D-4	Neutral 5 (.70)	49.51	0.7	0.92	1.16	50.49
	D-5	Neutral 3.5 (1.05)	34.97	0.7	0.5	0.86	65.03
	D-6	Black (1.50)	19.32	0.29	-0.16	0.33	80.68
					GS (C* Sum) =	10.71	

Sample: Unedited Generic Profile

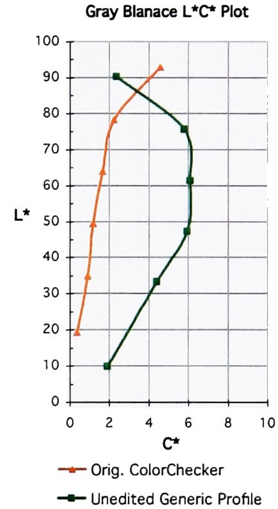
	Sample ID	SAMPLE_NAME	LAB_L	LAB_A	LAB_B	C*	Darkness	ΔEab	ΔE00
Unedited Generic Profile	A-1	Dark Skin	34.87	21.51	14.17	25.76	65.13		
	A-2	Light Skin	62.38	24.55	14.33	28.43	37.62		
	A-3	Blue Sky	46.98	-1.55	-26.32	26.37	53.02		
	A-4	Foliage	40.49	-10.97	23.25	25.71	59.51		
	A-5	Blue Flower	53.78	21.32	-23.26	31.55	46.22		
	A-6	Bluish Green	66.9	-24.62	-1.64	24.67	33.10		
	B-1	Orange	54.84	31.34	51.61	60.38	45.16		
	B-2	Purplish Blue	38.83	14.74	-44.11	46.51	61.17		
	B-3	Moderate Red	46.79	47.53	10.98	48.78	53.21		
	B-4	Purple	31.85	35.19	-21.46	41.22	68.15		
	B-5	Yellow Green	68.99	-15.6	52.25	54.53	31.01		
	B-6	Orange Yellow	65.19	15.86	55.05	57.29	34.81		
	C-1	Blue	27.59	22.3	-50.42	55.13	72.41		
	C-2	Green	52.61	-37.65	26.02	45.77	47.39		
	C-3	Red	40.13	55.96	31.18	64.06	59.87		
	C-4	Yellow	74.78	3.33	67	67.08	25.22		
	C-5	Magenta	49.79	52.52	-16.45	55.04	50.21		
	C-6	Cyan	48	-18.68	-26.13	32.12	52.00		
	D-1	White	90.37	-0.04	-2.34	2.34	9.63	7.34	6.64
	D-2	Neutral 8 (.23)	75.69	1.22	-5.65	5.78	24.31	8.02	7.09
	D-3	Neutral 6.5 (.44)	61.45	4.05	-4.55	6.09	38.55	6.92	6.56
	D-4	Neutral 5 (.70)	47.23	4.75	-3.58	5.95	52.77	6.47	6.81
	D-5	Neutral 3.5 (1.05)	33.41	3.73	-2.32	4.39	66.59	4.42	4.84
	D-6	Black (1.50)	9.86	0.01	-1.89	1.89	90.14	9.62	6.43
							ΔE average of neutrals:	7.13	6.40
							max ΔE of neutrals:	9.62	7.09

GS (C* Sum) = 26.44

Gray Balance a*b* Plot



Gray Blanace L*C* Plot



First Hypothesis: Gray Balance

Entered three sets of data (density, CIELAB, and spectral reflectance of the 24 patches).

Data set 1 Orig. ColorChecker

Data set 2 Custom Profile

Data set 3 Edited Custom Profile

Data set	Sample ID	SAMPLE_NAME	D_RED	D_GREEN	D_BLUE	D_VIS	LAB_L	LAB_A	LAB_B
Data set 1 Orig. ColorChecker	A-1	Dark Skin					37.3	15.44	15.7
	A-2	Light Skin					65.4	21.41	19.47
	A-3	Blue Sky					49.04	-4.21	-19.84
	A-4	Foliage					40.96	-14.44	23.76
	A-5	Blue Flower					54.37	9.77	-21.74
	A-6	Bluish Green					67.91	-31.22	0.09
	B-1	Orange					64.69	33.84	61.76
	B-2	Purplish Blue					38.76	8.79	-40.52
	B-3	Moderate Red					50.77	46.74	17.99
	B-4	Purple					30.48	22.42	-19.16
	B-5	Yellow Green					68.58	-20.54	54.05
	B-6	Orange Yellow					70.09	19.24	66.44
	C-1	Blue					28.7	13.86	-47
	C-2	Green					53.16	-36.94	30
	C-3	Red					42.36	53.46	27.36
	C-4	Yellow					77.59	5.78	74.54
	C-5	Magenta					50.51	48.62	-12.34
	C-6	Cyan					48.36	-25.95	-26.06
	D-1	White					93.01	1.19	4.4
	D-2	Neutral 8 (.23)					78.27	1.01	1.94
	D-3	Neutral 6.5 (.44)					64.09	1.14	1.15
	D-4	Neutral 5 (.70)					49.51	0.7	0.92
	D-5	Neutral 3.5 (1.05)					34.97	0.7	0.5
	D-6	Black (1.50)					19.32	0.29	-0.16
Data set 2 Custom Profile	A-1	Dark Skin					31.38	23.15	27.92
	A-2	Light Skin					60.82	21.73	12.38
	A-3	Blue Sky					43.62	-3.09	-28.46
	A-4	Foliage					37.02	-17.11	29.87
	A-5	Blue Flower					50.53	20.6	-25.59
	A-6	Bluish Green					64.94	-26.48	-3.87
	B-1	Orange					51.35	30.95	60.54
	B-2	Purplish Blue					33.49	15.4	-47.1
	B-3	Moderate Red					42.56	47.48	8.93
	B-4	Purple					26.51	41.81	-21.38
	B-5	Yellow Green					66.33	-17.15	56.04
	B-6	Orange Yellow					63.9	13.18	66.51
	C-1	Blue					18.46	20.62	-57.84
	C-2	Green					49.41	-41.19	30.83
	C-3	Red					35.2	56.18	34.97
	C-4	Yellow					73.59	3.38	77.34
	C-5	Magenta					45.94	52.19	-16.52
	C-6	Cyan					43.92	-24.35	-29.1
	D-1	White					89.81	-0.42	-2.96
	D-2	Neutral 8 (.23)					73.42	0.42	-6.46
	D-3	Neutral 6.5 (.44)					59.66	1.88	-5.82
	D-4	Neutral 5 (.70)					43.88	4.74	-4.68
	D-5	Neutral 3.5 (1.05)					27.18	2.82	-5.18
	D-6	Black (1.50)					6.81	0.25	-2.56
Data set 3 Edited Custom Profile	A-1	Dark Skin					33.93	20.78	27.02
	A-2	Light Skin					62.08	19.22	10.73
	A-3	Blue Sky					46.33	-3.26	-25.13
	A-4	Foliage					39.97	-17.96	30.16
	A-5	Blue Flower					52.1	17.95	-24
	A-6	Bluish Green					65.05	-24.61	-3.9
	B-1	Orange					52.58	27.6	59.59
	B-2	Purplish Blue					35.92	13.59	-44.86
	B-3	Moderate Red					44.88	43.41	6.58
	B-4	Purple					28.68	39.56	-22.39
	B-5	Yellow Green					66.47	-17.37	52.36
	B-6	Orange Yellow					64.52	10.78	62.51
	C-1	Blue					21.1	17.13	-57.77
	C-2	Green					51.03	-38.65	28.81
	C-3	Red					36.59	54.41	32.1
	C-4	Yellow					72.96	1.78	71.28
	C-5	Magenta					47.95	47.66	-16.92
	C-6	Cyan					45.89	-23.32	-27.48
	D-1	White					89.36	-0.18	-3.91
	D-2	Neutral 8 (.23)					77.88	-1.39	-6.19
	D-3	Neutral 6.5 (.44)					62.84	-1.5	-6.79
	D-4	Neutral 5 (.70)					48.98	-2.12	-2.25
	D-5	Neutral 3.5 (1.05)					34.48	-2.74	-3.21
	D-6	Black (1.50)					18.85	-0.39	4.42

Editing Custom ICC Profile: Raw Data

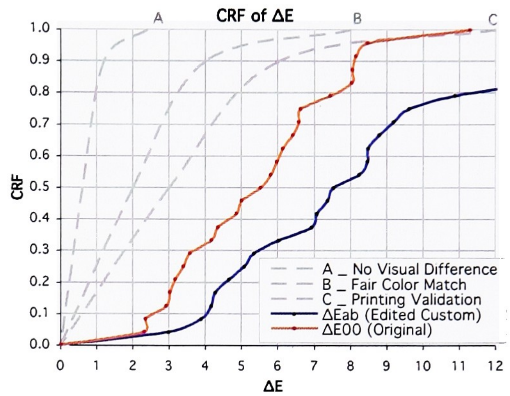
Observed ΔEs and its CRF between Original and Edited Custom ICC Profile

Select the **Reference**: Orig. ColorChecker

Select the **Sample**: Edited Custom Profile

Reference: Orig. ColorChecker

	Sample ID	SAMPLE_NAME	LAB_L	LAB_A	LAB_B
Orig. ColorChecker	A-1	Dark Skin	37.3	15.44	15.7
	A-2	Light Skin	65.4	21.41	19.47
	A-3	Blue Sky	49.04	-4.21	-19.84
	A-4	Foliage	40.96	-14.44	23 76
	A-5	Blue Flower	54.37	9.77	-21.74
	A-6	Bluish Green	67.91	-31.22	0.09
	B-1	Orange	64.69	33.84	61.76
	B-2	Purplish Blue	38.76	8.79	-40.52
	B-3	Moderate Red	50.77	46.74	17.99
	B-4	Purple	30.48	22.42	-19.16
	B-5	Yellow Green	68.58	-20.54	54.05
	B-6	Orange Yellow	70.09	19.24	66.44
	C-1	Blue	28.7	13.86	-47
	C-2	Green	53.16	-36.94	30
	C-3	Red	42.36	53.46	27.36
	C-4	Yellow	77.59	5.78	74.54
	C-5	Magenta	50.51	48.62	-12.34
	C-6	Cyan	48.36	-25.95	-26.06
	D-1	White	93.01	1.19	4.4
	D-2	Neutral 8 (.23)	78.27	1.01	1.94
	D-3	Neutral 6.5 (.44)	64.09	1.14	1.15
	D-4	Neutral 5 (.70)	49.51	0.7	0.92
	D-5	Neutral 3.5 (1.05)	34.97	0.7	0.5
	D-6	Black (1.50)	19.32	0.29	-0.16



Sample: Edited Custom Profile

	Sample ID	SAMPLE_NAME	LAB_L	LAB_A	LAB_B	ΔL*	Δa*	Δb*	(Edited Cu	:00 (Origir	CRF ΔEab	CRF ΔE00	CRF Y-axis
											0.00	0.00	0
Edited Custom Profile	A-1	Dark Skin	33.93	20.78	27.02	-3.37	5.34	11.32	12.96	6.57	2.98	2.31	0.04
	A-2	Light Skin	62.08	19.22	10.73	-3.32	-2.19	-8.74	9.60	6.12	3.88	2.33	0.08
	A-3	Blue Sky	46.33	-3.26	-25.13	-2.71	0.95	-5.29	6.02	3.56	4.17	2.91	0.13
	A-4	Foliage	39.97	-17.96	30.16	-0.99	-3.52	6.4	7.37	3.16	4.28	3.02	0.17
	A-5	Blue Flower	52.1	17.95	-24	-2.27	8.18	-2.26	8.78	5.79	4.65	3.16	0.21
	A-6	Bluish Green	65.05	-24.61	-3.9	-2.86	6.61	-3.99	8.23	4.84	5.08	3.39	0.25
	B-1	Orange	52.58	27.6	59.59	-12.11	-6.24	-2.17	13.79	11.29	5.33	3.56	0.29
	B-2	Purplish Blue	35.92	13.59	-44.86	-2.84	4.8	-4.34	7.07	3.02	6.02	4.17	0.33
	B-3	Moderate Red	44.88	43.41	6.58	-5.89	-3.33	-11.41	13.27	8.46	6.93	4.33	0.38
	B-4	Purple	28.68	39.56	-22.39	-1.8	17.14	-3.23	17.53	7.43	7.07	4.84	0.42
	B-5	Yellow Green	66.47	-17.37	52.36	-2.11	3.17	-1.69	4.17	2.31	7.37	5.00	0.46
	B-6	Orange Yellow	64.52	10.78	62.51	-5.57	-8.46	-3.93	10.86	6.61	7.53	5.52	0.50
	C-1	Blue	21.1	17.13	-57.77	-7.6	3.27	-10.77	13.58	6.41	8.23	5.79	0.54
	C-2	Green	51.03	-38.65	28.81	-2.13	-1.71	-1.19	2.98	2.33	8.46	5.97	0.58
	C-3	Red	36.59	54.41	32.1	-5.77	0.95	4.74	7.53	5.52	8.49	6.12	0.63
	C-4	Yellow	72.96	1.78	71.28	-4.63	-4	-3.26	6.93	4.17	8.78	6.41	0.67
	C-5	Magenta	47.95	47.66	-16.92	-2.56	-0.96	-4.58	5.33	3.39	9.18	6.57	0.71
	C-6	Cyan	45.89	-23.32	-27.48	-2.47	2.63	-1.42	3.88	2.91	9.60	6.61	0.75
	D-1	White	89.36	-0.18	-3.91	-3.65	-1.37	-8.31	9.18	8.14	10.86	7.43	0.79
	D-2	Neutral 8 (.23)	77.88	-1.39	-6.19	-0.39	-2.4	-8.13	8.49	8.02	12.96	8.02	0.83
	D-3	Neutral 6.5 (.44)	62.84	-1.5	-6.79	-1.25	-2.64	-7.94	8.46	8.04	13.27	8.04	0.88
	D-4	Neutral 5 (.70)	48.98	-2.12	-2.25	-0.53	-2.82	-3.17	4.28	5.00	13.58	8.14	0.92
	D-5	Neutral 3.5 (1.05)	34.48	-2.74	-3.21	-0.49	-3.44	-3.71	5.08	5.97	13.79	8.46	0.96
	D-6	Black (1.50)	18.85	-0.39	4.42	-0.47	-0.68	4.58	4.65	4.33	17.53	11.29	1.00
								ΔE average of 24 patches:	8.33	5.56			
								max ΔE of 24 patches:	17.53	11.29			

Editing Custom ICC Profile: ΔE Analysis

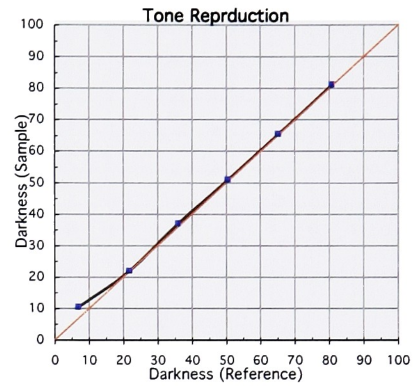
Shown Tone Reprduction in Terms of Original vs. Edited Custom ICC Profile

Orig. ColorChecker

Edited Custom Profile

Reference: **Orig. ColorChecker**

	Sample ID	SAMPLE_NAME	LAB_L	LAB_A	LAB_B	Darkness	Density
Orig. ColorChecker	A-1	Dark Skin	37.3	15.44	15.7	62.70	
	A-2	Light Skin	65.4	21.41	19.47	34.60	
	A-3	Blue Sky	49.04	-4.21	-19 84	50.96	
	A-4	Foliage	40.96	-14.44	23.76	59.04	
	A-5	Blue Flower	54.37	9.77	-21.74	45.63	
	A-6	Bluish Green	67.91	-31.22	0.09	32.09	
	B-1	Orange	64.69	33 84	61.76	35.31	
	B-2	Purplish Blue	38.76	8.79	-40.52	61.24	
	B-3	Moderate Red	50.77	46.74	17.99	49.23	
	B-4	Purple	30.48	22 42	-19.16	69.52	
	B-5	Yellow Green	68.58	-20.54	54.05	31.42	
	B-6	Orange Yellow	70.09	19 24	66.44	29.91	
	C-1	Blue	28.7	13.86	-47	71.30	
	C-2	Green	53.16	-36 94	30	46.84	
	C-3	Red	42.36	53.46	27.36	57.64	
	C-4	Yellow	77.59	5.78	74.54	22.41	
	C-5	Magenta	50.51	48.62	-12.34	49.49	
	C-6	Cyan	48.36	-25.95	-26.06	51.64	
	D-1	White	93.01	1.19	4.4	6.99	#N/A
	D-2	Neutral 8 (.23)	78.27	1.01	1.94	21.73	#N/A
	D-3	Neutral 6.5 (.44)	64.09	1.14	1.15	35.91	#N/A
	D-4	Neutral 5 (.70)	49.51	0.7	0.92	50.49	#N/A
	D-5	Neutral 3.5 (1.05)	34.97	0.7	0.5	65.03	#N/A
	D-6	Black (1.50)	19 32	0.29	-0.16	80 68	#N/A



Sample: **Edited Custom Profile**

	Sample ID	SAMPLE_NAME	LAB_L	LAB_A	LAB_B	Darkness	Density
Edited Custom Profile	A-1	Dark Skin	33.93	20.78	27.02	66.07	
	A-2	Light Skin	62.08	19.22	10.73	37.92	
	A-3	Blue Sky	46.33	-3.26	-25.13	53.67	
	A-4	Foliage	39 97	-17.96	30.16	60.03	
	A-5	Blue Flower	52.1	17.95	-24	47.90	
	A-6	Bluish Green	65.05	-24 61	-3.9	34.95	
	B-1	Orange	52.58	27.6	59.59	47.42	
	B-2	Purplish Blue	35 92	13.59	-44.86	64.08	
	B-3	Moderate Red	44.88	43.41	6.58	55.12	
	B-4	Purple	28.68	39.56	-22.39	71.32	
	B-5	Yellow Green	66.47	-17 37	52.36	33.53	
	B-6	Orange Yellow	64.52	10 78	62.51	35 48	
	C-1	Blue	21.1	17.13	-57.77	78.90	
	C-2	Green	51.03	-38.65	28.81	48.97	
	C-3	Red	36.59	54.41	32.1	63.41	
	C-4	Yellow	72.96	1.78	71.28	27.04	
	C-5	Magenta	47.95	47.66	-16.92	52.05	
	C-6	Cyan	45.89	-23.32	-27 48	54.11	
	D-1	White	89.36	-0.18	-3.91	10 64	#N/A
	D-2	Neutral 8 (.23)	77.88	-1.39	-6.19	22.12	#N/A
	D-3	Neutral 6.5 (.44)	62 84	-1.5	-6.79	37.16	#N/A
	D-4	Neutral 5 (.70)	48.98	-2.12	-2.25	51.02	#N/A
	D-5	Neutral 3.5 (1.05)	34.48	-2 74	-3.21	65.52	#N/A
	D-6	Black (1.50)	18 85	-0 39	4 42	81 15	#N/A

Editing Custom ICC Profile: Tone Reproduction

Compare colorimetric differences of neutrals a*b* diagram and L*C* plots.

Select the **Reference**: Orig. ColorChecker

Select the **Sample**: Edited Custom Profile

Reference: Orig. ColorChecker

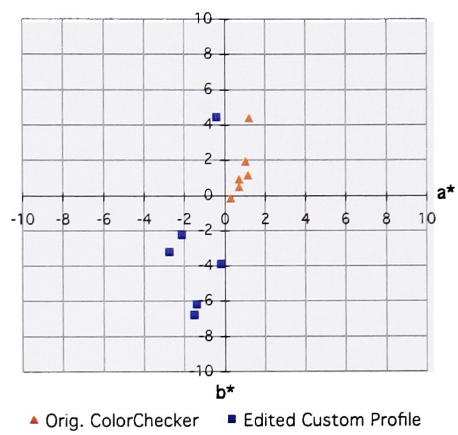
	Sample ID	SAMPLE_NAME	LAB_L	LAB_A	LAB_B	C*	Darkness
Orig. ColorChecker	A-1	Dark Skin	37.3	15.44	15.7	22.02	62.70
	A-2	Light Skin	65.4	21.41	19.47	28.94	34.60
	A-3	Blue Sky	49.04	-4.21	-19.84	20.28	50.96
	A-4	Foliage	40.96	-14.44	23.76	27.80	59.04
	A-5	Blue Flower	54.37	9.77	-21.74	23.83	45.63
	A-6	Bluish Green	67.91	-31.22	0.09	31.22	32.09
	B-1	Orange	64.69	33.84	61.76	70.42	35.31
	B-2	Purplish Blue	38.76	8.79	-40.52	41.46	61.24
	B-3	Moderate Red	50.77	46.74	17.99	50.08	49.23
	B-4	Purple	30.48	22.42	-19.16	29.49	69.52
	B-5	Yellow Green	68.58	-20.54	54.05	57.82	31.42
	B-6	Orange Yellow	70.09	19.24	66.44	69.17	29.91
	C-1	Blue	28.7	13.86	-47	49.00	71.30
	C-2	Green	53.16	-36.94	30	47.59	46.84
	C-3	Red	42.36	53.46	27.36	60.05	57.64
	C-4	Yellow	77.59	5.78	74.54	74.76	22.41
	C-5	Magenta	50.51	48.62	-12.34	50.16	49.49
	C-6	Cyan	48.36	-25.95	-26.06	36.78	51.64
	D-1	White	93.01	1.19	4.4	4.56	6.99
	D-2	Neutral 8 (.23)	78.27	1.01	1.94	2.19	21.73
	D-3	Neutral 6.5 (.44)	64.09	1.14	1.15	1.62	35.91
	D-4	Neutral 5 (.70)	49.51	0.7	0.92	1.16	50.49
	D-5	Neutral 3.5 (1.05)	34.97	0.7	0.5	0.86	65.03
	D-6	Black (1.50)	19.32	0.29	-0.16	0.33	80.68
					GS (C* Sum) =	10.71	

Sample: Edited Custom Profile

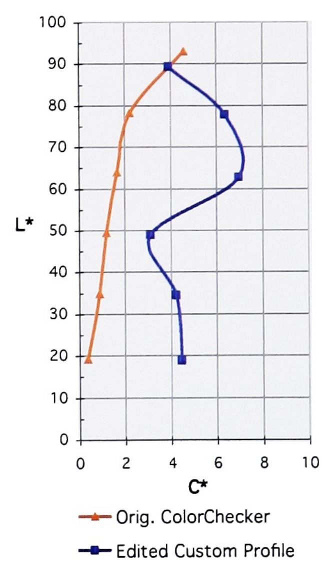
	Sample ID	SAMPLE_NAME	LAB_L	LAB_A	LAB_B	C*	Darkness	ΔEab	ΔE00
Edited Custom Profile	A-1	Dark Skin	33.93	20.78	27.02	34.09	66.07		
	A-2	Light Skin	62.08	19.22	10.73	22.01	37.92		
	A-3	Blue Sky	46.33	-3.26	-25.13	25.34	53.67		
	A-4	Foliage	39.97	-17.96	30.16	35.10	60.03		
	A-5	Blue Flower	52.1	17.95	-24	29.97	47.90		
	A-6	Bluish Green	65.05	-24.61	-3.9	24.92	34.95		
	B-1	Orange	52.58	27.6	59.59	65.67	47.42		
	B-2	Purplish Blue	35.92	13.59	-44.86	46.87	64.08		
	B-3	Moderate Red	44.88	43.41	6.58	43.91	55.12		
	B-4	Purple	28.68	39.56	-22.39	45.46	71.32		
	B-5	Yellow Green	66.47	-17.37	52.36	55.17	33.53		
	B-6	Orange Yellow	64.52	10.78	62.51	63.43	35.48		
	C-1	Blue	21.1	17.13	-57.77	60.26	78.90		
	C-2	Green	51.03	-38.65	28.81	48.21	48.97		
	C-3	Red	36.59	54.41	32.1	63.17	63.41		
	C-4	Yellow	72.96	1.78	71.28	71.30	27.04		
	C-5	Magenta	47.95	47.66	-16.92	50.57	52.05		
	C-6	Cyan	45.89	-23.32	-27.48	36.04	54.11		
	D-1	White	89.36	-0.18	-3.91	3.91	10.64	9.18	8.14
	D-2	Neutral 8 (.23)	77.88	-1.39	-6.19	6.34	22.12	8.49	8.02
	D-3	Neutral 6.5 (.44)	62.84	-1.5	-6.79	6.95	37.16	8.46	8.04
	D-4	Neutral 5 (.70)	48.98	-2.12	-2.25	3.09	51.02	4.28	5.00
	D-5	Neutral 3.5 (1.05)	34.48	-2.74	-3.21	4.22	65.52	5.08	5.97
	D-6	Black (1.50)	18.85	-0.39	4.42	4.44	81.15	4.65	4.33
							ΔE average of neutrals:	6.69	6.58
							max ΔE of neutrals:	9.18	8.14

GS (C* Sum) = 28.96

Gray Balance a*b* Plot



Gray Blanace L*C* Plot

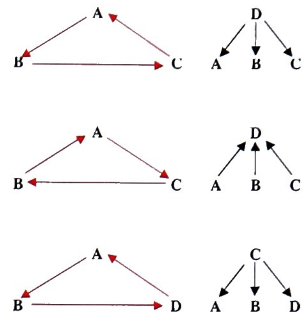


Editing Custom ICC Profile: Gray Balance

Appendix D

Visual Analysis

E. Summary of Subjective Image Quality Evaluation Landscape



The subject matter: Evaluation of reproduction quality of link profiling s/w

Date the experiment performed: 4/19/05
The number of judges participated: 10
The number of prints: 4

Print	Rank scores of all judges (add '1' to raw scores)										Ave.
	1	2	3	4	5	6	7	8	9	10	
A	4	3	4	4	3	4	3	3	2	3	3.30
B	3	1	1	1	4	1	2	3	2	3	2.10
C	1	4	2	2	2	2	4	3	2	1	2.30
D	2	2	3	3	1	3	1	1	4	3	2.30
Triad	0	0	0	0	0	0	0	1	1	1	

Note: Cut and paste row 10 -14 for consistent judges only.

Print	Judges who are consistent (0 triad)							Ave.
	1	2	3	4	5	6	7	
A	4	3	4	4	3	4	3	3.60
B	3	1	1	1	4	1	2	2.00
C	1	4	2	2	2	2	4	2.20
D	2	2	3	3	1	3	1	2.20

The number of judges who are consistent -----> 7

F. Ranking (Use only when there are 0 Triads)

		Description of Print Conditions
Best	A	Unedited Generic Profile
2nd	C	Unedited Custom Profile
3rd	D	Edited Custom Profile
Worst	B	Edited Generic Profile

Quick Summary
(1) The unedited generic profile did the best in matching the original lanscape watercolor painting.

F. Test for Agreement Among Judges

Print	Judges who are consistent							Col_9 Total for all judges	Col_10 *Average total (K37)	Col_11 Total - Average	Col_12 $(T-\bar{X})^2$
	1	2	3	4	5	6	7				
A	4	3	4	4	3	4	3	**25**		7.5	56.25
B	3	1	1	1	4	1	2	**13**	17.5	-4.5	20.25
C	1	4	2	2	2	2	4	**17**		-0.5	0.25
D	2	2	3	3	1	3	1	**15**		-2.5	6.25

Sum of all totals: 70 **Sum of squares (S): 83

Critical values for significance of agreement among judges, .05 level of significance

No. of Prints (P)	Number of Consistent Judges (J) 3	4	5	6	7
3			64.4	103.9	157.3
4		49.5	88.4	143.3	217.0
5		62.6	112.3	182.4	276.2
6		75.7	136.1	221.4	335.2

** The value of S (Sum of squares) must exceed the value shown in the above table to indicate a significant amount of agreement among judges.

Note: Col_9: Sum of all totals = Sum of all scores from all consistent judges
Col_10: *Average total = Sum of all totals / Number of prints
Col_11 = Col_9 - Col_10
Col_12 = Square of Col_11

Quick Summary
(1) Because the value, S (83) is less than the critical value (217.0), we conclude that there is no significant agreement among consistent judges.
(2) The correlation among jusges is low (0.23).

If the conclusion of the previous test is that the judges do in fact agree, a measure of the amount of agreement is found in the coefficient of concordance, W.

Formula: $W = 12 (S) / (J^2P(P^2 - 1))$
where J: Number of consistent judges 7
P: Number of prints 4
S: Sum of squares (cell O43) 83

W = 0.34

Note: 1. The value of W will equal 1.0 when there is perfect agreement among all judges, and equal 0.0 if there is no agreement.
2. The value of W is a measure of the total correlation when more than two judges are involved, and is an approximation of the average correlation between judges taken two at a time.
3. The exact value of the average correlation (R) can be computed from W by the following formula:

$R = (JW - 1) / (J - 1)$ R = 0.23
where J: Number of consistent judges
W: Coefficient of concordance

G. Test for Real Difference Among Prints

Judges who are consistent 7
The number of prints 4

Enter the table below. The row corresponds to the number of judges who are consistent. The column corresponds to the number of prints judged. For any print with real differences among other prints, its totals for that print (Col_9) must be lower than the first of the two values given in the Table below, or greater than the second value. The risk of error associated with the judgment that one or more prints differs from the others is 0.05.

No. of Prints (P)	Number of consistent judges (J) 3	4	5	6	7
3		5-11	6-14	8-16	10-18
4		5-15	7-18	9-21	11-24
5	4-14	6-18	8-22	10-26	12-30
6	4-17	6-22	9-26	11-31	14-35

Real difference among prints
(1) There is real difference between Print A and other prints; (2) There are no real differences among Print B, C, and D.

E. Summary of Subjective Image Quality Evaluation Portrait

The subject matter: Evaluation of reproduction quality of link profiling s/w

Date the experiment performed: 4/19/05
The number of judges participated: 10
The number of prints: 4

Print	Rank scores of all judges (add '1' to raw scores)									
	1	2	3	4	5	6	7	8	9	10
A	2	3	2	2	1	2	2	2	2	2
B	1	1	1	1	2	1	1	1	1	1
C	4	4	3	3	4	4	4	3	4	3
D	3	2	4	4	3	3	3	4	3	4
Triad	0	0	0	0	0	0	0	0	0	0

Ave.
2.00
1.10
3.60
3.30

Note: Cut and paste row 10 -14 for consistent judges only.

Print	Judges who are consistent (0 triad)							Ave.
	1	2	3	4	5	6	7	
A	2	3	2	2	1	2	2	2.00
B	1	1	1	1	2	1	1	1.20
C	4	4	3	3	4	4	4	3.60
D	3	2	4	4	3	3	3	3.20

The number of judges who are consistent -----> 7

F. Ranking (Use only when there are 0 Triads)

		Description of Print Conditions
Best	C	Unedited Custom Profile
2nd	D	Edited Custom Profile
3rd	A	Unedited Generic Profile
Worst	B	Edited Generic Profile

Quick Summary
(1) The unedited custom profile did the best in matching the original portrait watercolor painting.

F. Test for Agreement Among Judges

Print	Judges who are consistent							Col_9 Total for all judges	Col_10 *Average total (K37)	Col_11 Total - Average	Col_12 $(T-\bar{X})^2$
	1	2	3	4	5	6	7				
A	2	3	2	2	1	2	2	**14**	17.5	-3.5	12.25
B	1	1	1	1	2	1	1	**8**		-9.5	90.25
C	4	4	3	3	4	4	4	**26**		8.5	72.25
D	3	2	4	4	3	3	3	**22**		4.5	20.25

Sum of all totals: 70 **Sum of squares (S): 195

Critical values for significance of agreement among judges, .05 level of significance

No. of Prints (P)	Number of Consistent Judges (J)				
	3	4	5	6	7
3			64.4	103.9	157.3
4		49.5	88.4	143.3	217.0
5		62.6	112.3	182.4	276.2
6		75.7	136.1	221.4	335.2

** The value of S (Sum of squares) must exceed the value shown in the above table to indicate a significant amount of agreement among judges.

Note: Col_9: Sum of all totals = Sum of all scores from all consistent judges
Col_10: *Average total = Sum of all totals / Number of prints
Col_11 = Col_9 - Col_10
Col_12 = Square of Col_11

Quick Summary
(1) Because the value, S (195) is less than the critical value (217.0), we conclude that there is no significant agreement among
(2) The correlation among jusges is low (0.76).

If the conclusion of the previous test is that the judges do in fact agree, a measure of the amount of agreement is found in the coefficient of concordance, W.

Formula: $W = 12 (S) / (J^2P(P^2 - 1))$
where
J: Number of consistent judges 7
P: Number of prints 4
S: Sum of squares (cell O43) 195

W = 0.8

Note: 1. The value of W will equal 1.0 when there is perfect agreement among all judges, and equal 0.0 if there is no agreement.
2. The value of W is a measure of the total correlation when more than two judges are involved, and is an approximation of the average correlation between judges taken two at a time.
3. The exact value of the average correlation (R) can be computed from W by the following formula:

$R = (JW - 1) / (J - 1)$ R = 0.76
where
J: Number of consistent judges
W: Coefficient of concordance

G. Test for Real Difference Among Prints

Judges who are consistent 7
The number of prints 4

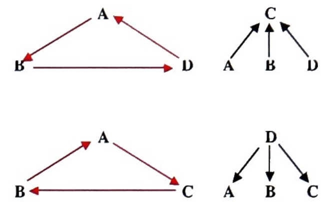
Enter the table below. The row corresponds to the number of judges who are consistent. The column corresponds to the number of prints judged. For any print with real differences among other prints, its totals for that print (Col_9) must be lower than the

No. of Prints (P)	Number of consistent judges (J)				
	3	4	5	6	7
3		5-11	6-14	8-16	10-18
4		5-15	7-18	9-21	11-24
5	4-14	6-18	8-22	10-26	12-30
6	4-17	6-22	9-26	11-31	14-35

Real difference among prints
(1) There are real difference between Print B, C and other prints; (2) There are no real differences among Print A and D.

E. Summary of Subjective Image Quality Evaluation

Still Life



The subject matter: Evaluation of reproduction quality of link profiling s/w

Date the experiment performed: 4/19/05
The number of judges participated: 10
The number of prints: 4

Print	Rank scores of all judges (add '1' to raw scores)										Ave.
	1	2	3	4	5	6	7	8	9	10	
A	1	4	3	2	1	2	3	2	2	3	2.30
B	2	1	1	1	3	1	1	1	2	3	1.60
C	4	2	2	3	4	4	4	3	4	3	3.30
D	3	3	4	4	2	3	2	4	2	1	2.80
Triad	0	0	0	0	0	0	0	0	1	1	

Note: Cut and paste row 10 -14 for consistent judges only.

Print	Judges who are consistent (0 triad)							Ave.
	1	2	3	4	5	6	7	
A	1	4	3	2	1	2	3	2.20
B	2	1	1	1	3	1	1	1.60
C	4	2	2	3	4	4	4	3.00
D	3	3	4	4	2	3	2	3.20

The number of judges who are consistent -----> 7

F. Ranking (Use only when there are 0 Triads)

		Description of Print Conditions
Best	D	Edited Custom Profile
2nd	C	Unedited Custom Profile
3rd	A	Unedited Generic Profile
Worst	B	Edited Generic Profile

Quick Summary
(1) The edited custom profile did the best in matching the original still-life watercolor painting.

F. Test for Agreement Among Judges

Print	Judges who are consistent							Col_9 Total for all judges	Col_10 *Average total (K37)	Col_11 Total - Average	Col_12 $(T-\bar{X})^2$
	1	2	3	4	5	6	7				
A	1	4	3	2	1	2	3	**16**	17.5	-1.5	2.25
B	2	1	1	1	3	1	1	**10**		-7.5	56.25
C	4	2	2	3	4	4	4	**23**		5.5	30.25
D	3	3	4	4	2	3	2	**21**		3.5	12.25

Sum of all totals: 70 **Sum of squares (S): 101

Critical values for significance of agreement among judges, .05 level of significance

No. of Prints (P)	Number of Consistent Judges (J) 3	4	5	6	7
3			64.4	103.9	157.3
4		49.5	88.4	143.3	217.0
5		62.6	112.3	182.4	276.2
6		75.7	136.1	221.4	335.2

** The value of S (Sum of squares) must exceed the value shown in the above table to indicate a significant amount of agreement among judges.

Note: Col_9: Sum of all totals = Sum of all scores from all consistent judges
Col_10: *Average total = Sum of all totals / Number of prints
Col_11 = Col_9 - Col_10
Col_12 = Square of Col_11

Quick Summary
(1) Because the value, S (101) is less than the critical value (217.0), we conclude that there is no significant agreement among
(2) The correlation among jusges is low (0.31).

If the conclusion of the previous test is that the judges do in fact agree, a measure of the amount of agreement is found in the coefficient of concordance, W.

Formula: $W = 12 (S) / (J^2P(P^2 - 1))$
where J: Number of consistent judges 7
P: Number of prints 4
S: Sum of squares (cell O43) 101

W = 0.41

Note: 1. The value of W will equal 1.0 when there is perfect agreement among all judges, and equal 0.0 if there is no agreement.
2. The value of W is a measure of the total correlation when more than two judges are involved, and is an approximation of the average correlation between judges taken two at a time.
3. The exact value of the average correlation (R) can be computed from W by the following formula:

$R = (JW - 1) / (J - 1)$ R = 0.31
where J: Number of consistent judges
W: Coefficient of concordance

G. Test for Real Difference Among Prints

Judges who are consistent **7**
The number of prints **4**

Enter the table below. The row corresponds to the number of judges who are consistent. The column corresponds to the number of prints judged. For any print with real differences among other prints, its totals for that print (Col_9) must be lower than the first of the two values given in the Table below, or greater than the second value. The risk of error associated with the judgment that one or more prints differs from the others is 0.05.

No. of Prints (P)	Number of consistent judges (J) 3	4	5	6	7
3		5-11	6-14	8-16	10-18
4		5-15	7-18	9-21	11-24
5	4-14	6-18	8-22	10-26	12-30
6	4-17	6-22	9-26	11-31	14-35

Real difference among prints
(1) There is real difference between Print B and other prints; (2) There are no real differences among Print A, C, and D.